DOCUMENT RESUME

ED 250 518 CE 040 042

TITLE	Robot Service and Repair. Student Guide.
INSTITUTION	Pittsburg State Univ., KS. Kansas Vocational Curriculum Dissemination Center.
PUB DATE	84
NOTE	354p.; For the teacher's guide, see CE 040 041.
PUB TYPE	Guides - Classroom Use - Materials (For Learner) (051)
EDRS PRICE	MF01/PC15 Plus Postage.
DESCRIPTORS	Behavioral Objectives; *Course Content; *Electronic Control; Electronics; Learning Activities; Learning Modules; *Lesson Plans; Man Machine Systems; Postsecondary Education; Power Technology; *Repair; *Robotics; Trade and Industrial Education

ABSTRACT

This document is a student guide for a course on robot service and repair. It is organized in four units covering the following topics: introduction to robots, power supply, robot control systems, and service and repair. Each unit contains several lesson plans on the unit topic. Lesson plans consist of lesson objectives, lists of teaching aids and informational assignments, references, information sheets, assignment sheets, and review questions. Information sheets are illustrated with line drawings. (KC)

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ROBOT SERVICE AND REPAIR

STUDENT GUIDE

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SYLLABUS SHEET FOR LESSON 1
ROBOT SERVICE AND REPAIR

UNIT #1 INTRODUCTION TO ROBOT

ROBOT HISTORY AND ITS TREND

LESSON OBJECTIVE--UPON COMPLETION OF THIS LESSON, THE STUDENT SHOULD BE ABLE TO:

1. TELL WHERE THE WORD "ROBOT" COMES FROM.
2. EXPLAIN THE DIFFERENCE OF HARD AUTOMATION DEVICES AND ROBOTICS.
3. LIST THE REASONS WHY INITIALLY U.S. INDUSTRY HAS NOT SHOWN AN INTEREST IN EMPLOYMENT OF ROBOTS IN APPLICATIONS OTHER THAN HOT, HEAVY, HAZARDOUS ENVIRONMENT.

TEACHING AIDS:

1.	H1-1-1	LESSON SYLLABUS SHEET
2.	T1-1 1	A HISTORY OF ROBOTS
3.	T1-1-2	A HISTORY OF UNIMATION
4.	T1-1-3	STATISTICS
5.	T1-1-4	U.S.-JAPAN COMPARISON ON INDUSTRIAL ROBOTS
6.	T1-1-5	WHY JAPAN IS SUCCESSFUL IN ROBOTIZATION

INFORMATIONAL ASSIGNMENTS:

1.	IS1-1-1	ROBOT HISTORY
2.	IS1-1-2	EVOLUTION OF INDUSTRIAL ROBOTS
3.	IS1-1-3	DOMESTIC VS FOREIGN DEVELOPMENT OF INDUSTRIAL ROBOTS
4.	IS1-1-4	FUTURE OF ROBOTS
		ANSWER QUESTIONS FOUND ON THE ABOVE ASSIGNMENT SHEETS
1.	AS1-1-1	ROBOT HISTORY AND ITS TREND

REFERENCES:

ENGELBERGER, J.F., ROBOTICS IN PRACTICE, AMERICAN MANAGEMENT ASSOCIATION, NEW YORK, 1980, PP. 1-7.

HSIC, A., INDUCTION TO ROBOTICS AND ITS TREND, SUNY COLLEGE OF TECHNOLOGY, NEW YORK, 1983.

STEP 1-INTRODUCTION FOR PREPARATION OF THE STUDENT:

ALTHOUGH THE "ROBOT" IDEA HAS BEEN IN OUR SOCIETY FOR SEVERAL DECADES, THE USE OF THE INDUSTRIAL ROBOT IN THE INDUSTRIAL ENVIRONMENT HAS NOT BEEN LONG.

DURING THE 1960-1970's PERIOD, MOST ROBOTS WERE USED RESTRICTEDLY IN HOT, HEAVY, AND HAZARDOUS AREAS. HOWEVER, AFTER 1976, JAPAN'S SUCCESS IN ROBOTICS APPLICATION AND PRODUCTION HAS CHANGED ALL CONCEPTS. THE REST OF THE WORLD HAS OVERWHELMINGLY ACCEPTED THE EMERGENCY OF THE ROBOT, AS A MODEL OF ANOTHER INDUSTRIAL REVOLUTION.

IN THIS UNIT, THE STUDENT WILL KNOW WHERE THE WORK "ROBOT" COMES FROM, WHEN IT IS USED IN REAL INDUSTRIAL OPERATIONS, HOW THE INDUSTRIAL ROBOT EVOLVED, AND THE ROBOTICS APPLICATION AND DEVELOPMENT FOR THE FUTURE.

LESSON SUMMARY AND REVIEW:

1. WHERE DOES "ROBOT" COME FROM?

2. WHAT DOES HARD AUTOMATION MEAN?

3. WHY IS THE U.S. INDUSTRY RELUCTANT TO USE ROBOTS IN ITS PRODUCTION LINE?

4. STATE THE FUTURE OF THE INDUSTRIAL ROBOTS.

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ROBOT HISTORY

THE POINT IN TIME THAT MARKS THE BEGINNING OF ROBOT TECHNOLOGY VARIES FROM AUTHOR TO AUTHOR.

FOR EXAMPLE, ROBERT MALONE IN HIS WORK, THE ROBOT BOOK, CHOSE TO BEGIN ROBOT HISTORY BY DISCUSSING THE CRUDE ANIMATED MACHINES OF ANCIENT EGYPT. MOST AUTHORS, HOWEVER, HAVE CHOSEN THE YEAR 1923 AS A SERIOUS STARTING POINT OF ROBOT HISTORY.

THE YEAR 1923 IS NOT ONLY CHOSEN BECAUSE IT MARKS ANY SIGNIFICANT ADVANCE IN ROBOT TECHNOLOGY, BUT ALSO BECAUSE IT MARKS THE YEAR THAT THE WORD "ROBOT" WAS INTRODUCED.

ROBOTS ENTERED THE ENGLISH VOCABULARY WITH THE TRANSLATION OF KAREL CAPEK'S PLAY R.U.R. (ROSSUM'S UNIVERSAL ROBOTS) IN 1923. CAPEK WAS A CZECH DRAMATIST, IN HIS PLAY THE WORD ROBOT WAS GENERATED. ROBOTS WERE THE HUMANIOD CREATIONS WHICH PERFORMED OBEDIENTLY IN THE SERVICE OF MANKIND. THE POPULAR CONCEPTION IS A MECHANICAL MAN, CRAMMED FULL OF NEAR-MIRACULOUS COMPONENTS, AND CAPABLE OF CLUMSY IMITATIONS OF HUMAN ACTION AND SPEECH. THEY ARE GENERALLY THOUGHT TO COMBINE SUPERHUMAN STRENGTH WITH SUBHUMAN INTELLIGENCE.

MID 1950'S THERE WERE SEVERAL ATTEMPTS TO BE MADE TO BUILD A ROBOT WITH INDUSTRIAL APPLICATIONS. DEVELOPMENT OF A WORK - PERFORMING ROBOT HAD TO AWAIT TECHNOLOGICAL ADVANCES IN THE AREA OF MINIATURE CONTROLS, MOTORS AND FEEDBACK DEVICES.

THE NASCENT OF ROBOTS IN INDUSTRY OCCURRED IN 1961 WHEN GENERAL MOTORS INTRODUCED ROBOTS INTO ITS AUTO PRODUCTION OPERATION. THE MAN MOST RESPONSIBLE FOR DEVELOPING THE ROBOTS USED IN G.M.'S FIRST ROBOT APPLICATIONS WAS JOSEPH F. ENGELBERGER, A ROBOT INNOVATOR SINCE THE MID 50'S. ENGELBERGER DID MORE THAN ANYONE ELSE TO BRING ROBOTS INTO INDUSTRY. HE IS NOW WIDELY RECOGNIZED AS THE "FATHER OF ROBOTS."

ALTHOUGH ENGELBERGER AND GENERAL MOTOR HAD PROVED THAT ROBOT APPLICATIONS IN INDUSTRY WERE POSSIBLE AND PROFITABLE, ROBOTS IN GENERAL WERE NOT ACCEPTED WITH OPEN ARMS BY U.S. INDUSTRIES. DURING THE 1960 AND 1970'S, ROBOT USE WAS PRIMARILY RESTRICTED TO APPLICATIONS THAT WERE HOT, HEAVY, AND HAZARDOUS.

ROBOT HISTORY (CONT.)

IN 1971, JAPANESE AUTO CAME TO UNIMATION TO BUY ROBOTS. FIVE YEARS LATER, THE JAPANESE SUCCESSFUL STORIES IN ROBOT APPLICATIONS HAD BEEN OVERWHELMINGLY ACCEPTED BY THE REST OF THE WORLD AS A MODEL OF ANOTHER INDUSTRIAL REVOLUTION.

EVOLUTION OF INDUSTRIAL ROBOTS (CONT.)

THE LAST AND GREATEST ADVANCEMENT WAS THE ADAPTATION OF COMPUTER CONTROL. THIS DELUXE, GENERAL-PURPOSE ROBOT, EQUIPPED WITH THE LATEST IN COMPUTER CONTROL TECHNOLOGICAL CAPABLE OF ALL SORTS OF MOTIONS WAS AN OVERSKILL IN MANY APPLICATIONS. THIS CHANGE WAS MADE POSSIBLE BY THE RAPID DEVELOPMENT OF THE MICROPROCESSOR FOR ROBOT CONTROL, THUS, LOW COST MICROPROCESSOR CONTROLLERS MADE THESE SPECIAL-PURPOSE ROBOTS A STILL GREATER ASSET TO THE MANUFACTURING AND INDUSTRIAL COMMUNITY.

EVOLUTION OF INDUSTRIAL ROBOTS

THE PRINCIPLE TECHNOLOGICAL CONTEXT OF ROBOTICS IN THE FIELD OF INDUSTRIAL AUTOMATION. INDUSTRIAL ROBOTS HAVE EMERGED FROM "HARD AUTOMATION" WHICH CAN BE DESCRIBED AS EQUIPMENT DESIGNED TO ACCOMPLISH REPETITIVE PRODUCTION LINE TASKS AT A FAST PACE. A HARD AUTOMATION DEVICE CONSISTS PRIMARILY OF DRIVE MECHANISM CONTROLLED BY DEVICES SUCH AS TIMERS, CAMS, SWITCHES, AND MECHANICAL AND ELECTRICAL STOPS. THE FUNCTION OF HARD AUTOMATION IS USUALLY VERY SPECIFIC, AND THERE IS SELDOM A NEED TO ALTER ITS OPERATION. WHEN CHANGES ARE REQUIRED, IT IS OFTEN ONLY A MECHANICAL ADJUSTMENT. BECAUSE OF THIS, THERE IS USUALLY NO CAPABILITY WITHIN THE EQUIPMENT TO RESPOND TO DEVIATION FROM THE MAUFACTURING PROCESS, EXCEPT PERHAPS AUTOMATION SHUTDOWN.

THE EVOLUTION FROM HARD AUTOMATION TO ROBOTS HAS BEEN IN A SERIES OF DEVELOPMENT STAGES. WHEN SPEED CONTROLLERS, SEQUENCERS, ADJUSTABLE STOPS, TIMERS, AND OTHER DEVICES WHICH PERMITTED VARIATIONS IN ITS MOTIONS WERE ADDED TO THESE HARD AUTOMATIONS, THEY BECAME THE FOREFATHERS OF TODAY'S ROBOT.

THE NEXT STEP IN ROBOT EVOLUTION WAS THE ADDITION OF SERVO CONTROLS. THESE FEEDBACK DEVICES GENERATED POSITION SIGNALS. WHEN THE ROBOT MOVED, THESE POSITION SIGNALS WERE COMPARED TO THE ORIGINAL INPUT POSITIONING SIGNALS AND, ONCE THESE TWO SIGNALS COINCIDED, THE ROBOT CEASED MOVEMENT. THESE KINDS OF CONTROLS ARE THE VERY SAME TECHNIQUES USED IN COMPUTERS AND IN NUMERICALLY CONTROLLED MACHINE TOOLS.

THIS COMMON ROOT MEANS THAT COMMUNICATION LINKS CAN BE ESTABLISHED BETWEEN ROBOTS AND COMPUTERS, AND BETWEEN ROBOTS AND NC MACHINES. THIS OPENS UP EXCITING FUTURE POSSIBILITIES FOR OPERATING ROBOTS DIRECTLY FROM COMPUTERS: OR FOR SYNCHRONIZING THEN WITH NC MACHINES. COMPANIES WHICH USE COMPUTERS FOR DESIGN (CAD) MIGHT EVEN BE ABLE TO HAVE THEIR COMPUTER DESIGN THE PRODUCT AND PRODUCE THE ROBOT CONTROL PROGRAMS SO THAT NOT ONLY THE HUMAN MACHINE OPERATOR IS REPALCED, BUT THE DRAFTSMAN AS WELL.

DOMESTIC vs FOREIGN DEVELOPMENT OF INDUSTRIAL ROBOTS

ALTHOUGH MOST OT THE IMPORTANT WORK IN ROBOT TECHNOLOGY WAS CONDUCTED IN THE U.S. DURING THE EARLY SIXTIES, ACCEPTANCE OF THE INDUSTRIAL ROBOT BY U.S. INDUSTRY NEVER MATERIALIZED. THE RELUCTANCE OF U.S. INDUSTRY TO EMPLOY ROBOTS IN OTHER THAN APPLICATIONS THAT WERE HOT, HEAVY AND HAZARDOUS CAN BE ATTRIBUTED TO SEVERAL FACTORS: HIGH INITIAL COST AND EXTENDED PAYBACK PERIODS, LABOR'S NEGATIVE REACTION TO ROBOTS, GOVERNMENTS FAILURE TO RECOGNIZE ROBOTS AS A MEANS OF INCREASING THE COUNTRY'S PRODUCTIVITY AND THEREBY PROMOTING THEIR USE THROUGH TAX INCENTIVES AND OTHER POLICIES AND PROGRAMS, AND SHORTSIGHTED MANAGERS IN MOST U.S. FACTORIES.

THE ABOVE MENTIONED IMPEDIMENTS TO WIDESPREAD DOMESTIC USE AND DEVELOPMENT OF THE INDUSTRIAL ROBOTS WERE NOT ENCOUNTERED OR WERE NOT AS SEVERE IN INDUSTRIALIZED NATIONS SUCH AS WEST GERMANY AND JAPAN. THE INDUSTRIAL COMMUNITIES OF THESE COUNTRIES RECOGNIZED THE PRODUCTIVITY AND PRODUCT QUALITY GAINS TO BE MADE FROM THE APPLICATION OF ROBOT TECHNOLOGY AND APPLIED IT MORE EXTENSIVELY THAN IN THE U.S.

FOREIGN DEVELOPMENT OF ROBOT TECHNOLOGY IS NOWHERE MORE EVIDENT THAN IN JAPAN. THE JAPANESE HAVE BECOME WORLD LEADERS IN THE APPLICATION OF ROBOT TECHNOLOGY WITH NEARLY HALF OF THE WORLD'S ROBOTS WORKING IN JAPANESE INDUSTRIES.

JAPAN'S LEADERSHIP IN THE APPLICATION OF ROBOT TECHNOLOGY DID NOT COME ABOUT BY CHANCE, BUT WAS CULTIVATED BY A STRONG COMMITTMENT FROM GOVERNMENT AND INDUSTRY AND NURTURED BY SOME UNIQUE SOCIAL ASPECTS OF THE HAPANESE CULTURE.

THE JAPANESE GOVERNMENT THORUGH THE MINISTRY OF TRADE AND INDUSTRY (MITI) HAS PROMOTED ROBOT UTILIZATION SINCE THE EARLY 70'S. THE MITI, RECOGNIZING THE WORLD TRADE ADVANTAGES THAT COULD BE REALIZED FROM THE ROBOTIZATION OF JAPANESE INDUSTRY AND THE VAST POTENTIAL WORLD MARKET FOR ROBOT TECHNOLOGY TOOK ACTION TO ENCOURAGE ROBOT USE AND DEVELOPMENT. THE MITI'S ACTIONS WERE BROAD-BASED AND TOUCHED ON FINANCING, TAXES AND RESEARCH AND DEVELOPMENT. IN THE AREA OF FINANCING THE MITI ARRANGED FOR DIRECT GOVERNEMNT LOW-INTEREST LOANS TO SMALL AND MEDIUM SIZED FIRMS FOR THE PURCHASE OF ROBOTS.

ALSO, THE MITI SUPPORTED THE FOUNDING OF A ROBOT LEASING COMPANY, JAPAN ROBOT LEASE. IN THE AREA OF TAXES THE MITI ALLOWS FOR ACCELERATED DEPRECIATION OF ROBOT EQUIPMENT: 12.5% OF THE INTIAL PRICE OF THE EQUIPMENT IN ADDITION TO THE ORDINARY DEPRECIATION ALLOWANCE IS ALLOWED IN THE FIRST YEAR. SUCH TAX ADVANTAGES HELP TO IMPROVE PAYBACK ON ROBOT PROJECTS, THUS MAKING THEM MORE ATTRACTIVE TO INDUSTRY. MITI'S R&D EFFORTS ARE IMPRESSIVE AND INCLUDE A 150 MILLION, SEVEN YEAR NATIONAL ROBOT RESEARCH PROGRAM.

FUTURE OF ROBOTS

THE FUTURE IS BRIGHT FOR THE INDUSTRIAL ROBOT WORLDWIDE. JAPAN, WEST GERMANY AND FRANCE, AS WELL AS THE U.S., ARE MOVING STRONGLY AHEAD NOT ONLY IN APPLICATIONS BUT IN PRODUCTION OF ROBOTS. COMPANIES LIKE JAPAN'S FUJITSU FANUC LTD WHICH HAS BUILT A 38 MILLION DOLLAR PLANT THAT USES NC MACHINES AND ROBOTS TO PRODUCE OTHER ROBOTS ARE SETTING THE PACE AND COMPETIION IS STRONG. IN THE COMMUNIST WORLD, THE SOVIET UNION JUST CAME OUT WITH A NEW FIVE-YEAR PLAN WHICH INCLUDED A SCHEDULE THAT WILL MANUFACTURE 40,000 ROBOTS TO HELP THEIR SHORTAGE OF LABOR FORCE. DEVELOPING COUNTRIES SUCH AS TAIWAN HAS CLAIMED ITS INTENTION TO JOIN THE ROBOT-HEAT IN THE NEXT ONE OR TWO YEARS.

IN THE U.S., ROBOTS ARE SEEN AS THE KEY TO INCREASED PRODUCTIVITY WHICH IS NEEDED TO MAKE INDUSTRY WHOLE AGAIN. COMPANIES LIKE UNIMATION INC., CINCINNATI MILACRON, PRAB, GENERAL ELECTRIC ARE COMPETING STRONGLY FOR ITS SHARE OF THE WORLD ROBOT MARKET. ROBOTS ARE BEING VIEWED AS THE NEW SAVIOR OF THE FALTERING U.S. ECONOMY BY BOTH GOVERNMENT AND INDUSTRY. MARKET PROJECTIONS ARE INCREASING STEADILY WITH ALL INDICATIONS BEING THAT THE MANUFACTURES OF ROBOTS WILL BE ONE OF THE HIGH TECHNOLOGY GROWTH INDUSTRIES IN THE FUTURE.

THE ROBOTIZATION OF U.S. INDUSTRY MEANS MORE THAN JUST INCREASED PRODUCTIVITY AND ITS POSITIVE ECONOMIC EFFECTS, THERE ARE ALSO THE SOCIAL CONSEQUENCES TO CONSIDER. FOR EXAMPLE, WHO IS TO BEAR THE HUGE COST OF RETAINING WORKERS THAT ARE DISPLACED? JAMES ALBUS IN HIS WORK PEOPLE'S CAPITALISM POSES SOME PROVOCATIVE QUESTIONS ON THE SOCIALECONOMIC ASPECTS OF ROBOTIZATION:

> IF ROBOTS EVENTUALLY DO MOST OF THE ECONOMICALLY PRODUCTIVE WORK, HOW WILL PEOPLE RECEIVE AN INCOME? WHO WILL OWN THESE MACHINES AND WHO WILL CONTROL THE POWERFUL AND ECONOMIC AND POLITICAL FOCUS THEY REPRESENT?

THESE ARE HARD QUESTIONS AND THE ANSWERS SELECTED BY SOCIETY TO THESE QUESTIONS WILL SHAPE THE FUTURE OF THE INDUSTRIAL ROBOT.

LESSON PLAN #1

UNIT 1--ROBOT HISTORY AND ITS TREND

ASSIGNMENT SHEET 1

AFTER READING THE INFORMATION SHEET (IS1-1-1 AND IS1-1-4) PROVIDED, COMPLETE THE FOLLOWING QUESTIONS IN WRITING OR AS REQUESTED BY YOUR INSTRUCTOR.

1. WHY DID MOST AUTHORS CHOOSE THE YEAR 1923 AS A STARTING POINT OF ROBOT HISTORY?

2. WHAT IS THE DIFFERENCE BETWEEN HARD AUTOMATION DEVICE AND ROBOTS?

3. LIST FOUR REASONS THAT PRESENT THE USE AND DEVELOPMENT OF INDUSTRIAL ROBOT IN THE USA.
    1.

    2.

    3.

    4.

4. WHY ARE ROBOTS NOT A THREAT TO THE WORKERS IN JAPAN?

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5. IN THE YEAR ________ THE WORD "ROBOT" WAS INTRODUCED INTO THE ENGLISH VOCABULARY.

6. HARD AUTOMATION DEVICES ARE _________________ ALTERED TO CHANGE THEIR OPERATION.

7. THE GREATEST ADVANCEMENT IN THE EVOLUATION OF THE ROBOT WAS THE ADAPTATION OF _________________ CONTROL.

8. THE _________________ HAVE BECOME WORLD LEADERS IN THE APPLICATION OF ROBOT TECHNOLOGY WITH NEARLY HALF OF THE WORLD'S ROBOTS WORKING IN ITS COUNTRY TODAY.

9. THE ROBOTIZATION OF U.S. INDUSTRY MEANS MORE THAN JUST INCREASED __________________________ AND ITS POSITIVE _____________________ EFFECTS, THERE ARE ALSO THE SOCIAL CONSEQUENCES TO CONSIDER.

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SYLLABUS SHEET FOR LESSON 1
ROBOT SERVICE AND REPAIR

UNIT #1 INTRODUCTION TO ROBOT

SOCIO-ECONOMIC IMPACT OF ROBOT

LESSON OBJECTIVE--UPON COMPLETION OF THIS LESSON, THE STUDENT SHOULD BE ABLE TO:

1. STATE THE EMPLOYMENT OF INDUSTRIAL ROBOTS IN DIFFERENT PRODUCTION SCENES.
2. DESCRIBE THE FUNCTIONS OF INDUSTRIAL ROBOTS.
3. COMPARE THE ROBOT COST WITH HUMAN LABOR COST.
4. EXPLAIN THE RELATIONSHIP AMONG MAN, ROBOT, AND SPECIAL AUTOMATION.

TEACHING AIDS:

1. H1-2-1 SYLLABUS SHEET
2. T1-2-1 REASONS FOR USING ROBOTS FOR SELECTED APPLICATIONS
3. T1-2-2 A COMPARISON OF UNIT COSTS FOR MANUFACTURING METHODS BY LEVEL OF PRODUCTION
4. T1-2-3 THE FUNCTIONS OF INDUSTRIAL ROBOTS
5. T1-2-4 ROBOT COST vs. HUMAN COST
6. T1-2-5 MAN vs. ROBOT vs. SPECIAL AUTOMATION

REFERENCES:

DROF, RICHARD C., ROBOTICS AND AUTOMATED MANUFACTURING, RESTON PUBLISHING COMPANY, INC., 1983.

ENGELBERGER, JOSEPH F., ROBOTICS IN PRACTICE, AMERICAN MANAGEMENT ASSOCIATION, NEW YORK, 1980.

STEP 1-INTRODUCTION FOR PREPARATION OF THE STUDENT:

PRODUCTIVITY IS ONE MAJOR GOAL OF THE INDUSTRIES OF TODAY. THIS GOAL IS NOT ONLY TO INCREASE THE COMPETIVENESS OF INDUSTRIES BUT ALSO TO IMPROVE ITS ECONOMIC EFFECTS.

IN ORDER TO ACHIEVE THE GOALS, THE INDUSTRIES HAVE RECOGNIZED THE APPLICATION OF ROBOT TECHNOLOGY AS AN IMPORTANT TOOL. THE USE OF ROBOTS MAY LOWER PRODUCTION COSTS, IMPROVE THE QUALITY OF PRODUCTS AND REDUCE WORKPLACE HAZARDS. A CLEAR THEME HAS BEEN THE CONCERN THAT FOREIGN COMPETITORS MAY BE GAINING A SIGNIFICANT EDGE OVER THE U.S., BOTH IN USING THIS NEW TECHNOLOGY AND IN ESTABLISHING A COMPETITIVE POSITION IN THE POTENTIALLY MAJOR EXPORT MARKET FOR ROBOTS.

IN THIS LESSON, THE STUDENT WILL UNDERSTAND THE REASONS FOR USING INDUSTRIAL ROBOTS, THEIR FUNCTIONS, AND BE ABLE TO COMPARE THE COSTS OF MAN, ROBOTS AND SPECIAL AUTOMATION.

LESSON SUMMARY AND REVIEW:

1. WHAT ARE THE THREE CHARACTERISTICS OF THE INDUSTRIAL ROBOTS?

2. EXPLAIN WHY A FIRM APPLIES INDUSTRIAL ROBOTS IN ITS PRODUCTION LINE TO IMPROVE OPERATING RATIO AND INCREASE OPERATING TIME.

3. WHAT ARE THE FUNCTIONS OF INDUSTRIAL ROBOTS?

4. COMPARE THE ROBOT COST WITH HUMAN LABOR COST.

5. DESCRIBE THE RELATIONSHIP AMONG MAN, ROBOT, AND SPECIAL AUTOMATION.

THE THREE CHARACTERISTICS OF INDUSTRIAL ROBOTS

INDUSTRIAL ROBOTS HAVE THREE MAJOR CHARACTERISTICS WHICH, IN LARGE MEASURE, DETERMINE THEIR SOCIO-ECONOMIC IMPACT:

1. INDUSTRIAL ROBOTS, UNLIKE SPECIAL PURPOSE AUTOMATED MACHINES, ARE PROGRAMMABLE, AND AS A CONSEQUENCE, ARE BOTH FLEXIBLE AND VERSATILE. A ROBOT'S MOVEMENTS MAY BE ALTERED MERELY BY CHANGING ITS PROGRAM.

2. INDUSTRIAL ROBOTS CAN PERFORM BEYOND THE PHYSICAL AND MECHANICAL ABILITIES OF HUMANS. THEY DO NOT TIRE FROM LONG AND CONTINUOUS HOURS OF WORK IN AN ENVIRONMENT WHICH MAY BE UNCOMFORTABLE, IF NOT HAZARDOUS TO HUMANS. ROBOTS REQUIRE NO BREAKS TO OVERCOME FATIGUE OR TO MEET PERSONAL NEEDS.

3. INDUSTRIAL ROBOTS PERFORM WITH HIGH FIDELITY AND ACCURACY IN COMPLIANCE WITH THE INSTRUCTION WHICH THEY RECEIVE FROM MAN.

AS A RESULT OF THEIR VERSATILITY, SUPER-HUMAN CAPABILITY, AND HIGH FIDELITY TO PROGRAMMING, INDUSTRIAL ROBOTS HAVE CHANGED IN MANY WAYS THE PRODUCTION SCENE IN WHICH THEY ARE EMPLOYED.

THE EMPLOYMENT OF ROBOTS IN DIFFERENT PRODUCTION SCENES

1. AUTOMATION OF MULTI-PRODUCT SMALL BATCH AND MIXED-FLOW-PRODUCTION LINE: THE FLEXIBILITY AND VERSATILITY OF INDUSTRIAL ROBOTS MAKE POSSIBLE THE AUTOMATION OF MULTI-PRODUCT SMALL BATCH AND MIXED-FLOW-LINE PRODUCTION. THE SPECIAL PURPOSE AUTOMATED MACHINE IS RESTRICTED TO LIMITED MODEL MASS PRODUCTION. RECENTLY, CONSUMER DEMAND HAS BECOME INCREASINGLY DIVERSIFIED TO THE POINT WHERE ACCORDING TO JAPANESE ESTIMATES, FULLY 80% OF MECHANIZED INDUSTRY'S PRODUCTS ARE MANUFACTURED IN A MODERATE-TO-LOW VOLUME OF OUTPUT. THUS, THE NATURE OF CONTEMPORARY CONSUMER DEMAND AND PARTICULARLY JAPAN'S DESIRE TO ACCOMMODATE A WIDE DIVERSITY OF EXPORT REQUIREMENTS NECESSITATED AND ENCOURAGED THE USE OF INDUSTRIAL ROBOTS.

2. EASE OF PHASING IN PRODUCT DESIGN MODIFICATION AND MODEL CHANGEOVER: A COMPLETE CHANGEOVER OR EVEN A MODIFICATION IN A PRODUCT MODEL OFTEN REQUIRE CHANGING OR AT LEAST RADICALLY REBUILDING A SPECIAL PURPOSE AUTOMATED MACHINE. WHERE AN INDUSTRIAL ROBOT IS USED INSTEAD, A MERE CHANGE IN PROGRAM IS REQUIRED. AS THE PRODUCT LIFE CYCLE SHORTENS, THE FLEXIBILITY AND VERSATILITY OF INDUSTRIAL ROBOTS BECOME INCREASINGLY ADVANTAGEOUS.

3. IMPROVED OPERATING RATIO AND INCREASED OPERATING TIME: UNLIKE MEN, INDUSTRIAL ROBOTS CAN OPERATE ON A 24-HOUR BASIS AND THEREFORE, THE MACHINES, THEY SERVICE CAN ALSO OPERATE ON A 24-HOUR BASIS. FURTHERMORE, INDUSTRIAL ROBOTS ARE CAPABLE OF PERFORMING FUNCTIONS AT A HIGH SPEED WHICH EXCEED HUMAN LIMITATIONS.

4. ABILITY TO WITHSTAND SEVERE WORKING CONDITIONS: THE INDUSTRIAL ROBOT CAN WORK IN AN ENVIRONMENT WHICH IS ADVERSE TO HUMANS. HUMAN BEINGS REQUIRE A HOST OF CONDITIONS TO MAKE THE WORKING ATMOSPHERE BOTH PLEASANT AND SAFE--VENTILATION, PROPER LIGHTING, AIR CONDITIONING, OR AT LEAST TEMPERATURE CONTROL, AND A VARIETY OF SAFETY DEVICES AND CONDITIONS.

5. ABILITY TO EXECUTE ACCURATE MOTIONS AND THE ABILITY TO COPE ELASTICALLY WITH CHANGING PRODUCTION VOLUME: THE SUSTAINED STABILITY OF INDUSTRI[illegible] ROBOT OPERATION--THEIR ABILITY TO WORK CONTINUOUSLY AND ACCURATELY FAITHFUL TO THEIR MAN-GIVEN INSTRUCTIONS ELIMINATES SLUMPS AND SPURTS AND PROVIDES A SMOOTHER PRODUCTION FLOW. THIS ABILITY ALSO ENABLES INCREASED PRODUCTION DEMANDS TO BE MET EFFECTIVELY.

6. CHANGING IN NATURE OF PRODUCTION SYSTEM: THE INTRODUCTION OF INDUSTRIAL ROBOTS MEANS A CHANGE IN THE PRODUCTION SYSTEM. IN THE TYPICAL TRADITIONAL MASS PRODUCTION LINE, THE MACHINE DETERMINES THE ACTIVITY OF THE OPERATORS. THE OPERATOR PROGRAMS THE INDUSTRIAL ROBOT AND THEREFORE, THE HUMAN DOMINATES THE SYSTEM. THE INDUSTRIAL ROBOT REDUCED THE PSYCHOLOGICAL RESISTANCE TO THE CONVEYOR SYSTEM AND THUS PERMITTED ITS MORE EFFECTIVE USE. THEY BELIEVE HUMAN SATISFACTION IS DERIVED FROM THE HUMAN CONTROL OVER THE ROBOT AND THIS ATTITUDE LED TO QUALITATIVE IMPROVEMENT IN LABOR.

7. CREATION OF NEW TECHNOLOGIES: THE CHARACTERISTICS OF THE INDUSTRIAL ROBOTS COMBINED WITH THE CHANGE IN THE PRODUCTION SYSTEM TO A MAN-DOMINATED ROBOT-MACHINE SYSTEM LED TO THE CREATION OF COMPLETELY NEW TECHNOLOGIES AND TO THEIR APPLICATION IN EXPLOITING OCEANIC RESOURCES AND IN INCREASING UTILIZATION OF NUCLEAR ENERGY. ROBOT APPLICATION TO HEALTH, HOUSEHOLD, AND CLEANING DUTIES HAVE ALSO BEEN FORECAST.

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THE REASONS FOR USING INDUSTRIAL ROBOTS

ROBOTS ARE USED IN FACTORY APPLICATIONS BECAUSE OF SEVERAL ECONOMIC AND OTHER CONSIDERATIONS, AS SHOWN IN FIGURE 2-1. REDUCED DIRECT LABOR COST IS THE PRIMARY CONSIDERATION IN THE CASE OF WELDING, MATERIAL HANDLING, AND MACHINERY: HOWEVER, IN PAINTING THE REDUCTION OR ELIMINATION OF HAZARDOUS, UNPLEASANT WORK IS PARAMOUNT.

	Reduction in direct labor costs	Increase in productivity	Hazardous, unpleasant work	Improved product quality
WELDING	1	2	4	3
MATERIAL HANDLING	1	3	2	4
MACHINING	1	2	4	3
MACHINE LOADING	2	1	3	4
ASSEMBLY	2	1	4	3
SPRAY PAINTING	3	4	1	2

Fig. 2-1 Reason for using robots for selected application.

IN GENERAL, FIRMS THAT CAN EFFECTIVELY USE ROBOTS HAVE A PRODUCTION VOLUME REQUIREMENT THAT LIES BETWEEN MANUAL OPERATION AND FIXED OR HARD AUTOMATION (SEE FIGURE 2-2). ALTHOUGH SOME ROBOTS ARE INSTALLED IN DEVELOPMENT SITUATIONS OR TO REMOVE WORKERS FROM A HOSTILE ENVIRONMENT, IT IS APPARENT THAT THE PRIME MOVER IN ADOPTION OF AN INDUSTRIAL ROBOT IS PRODUCTIVITY. IF THERE IS NOT ENOUGH DIRECT AND INDIRECT LABOR SAVINGS TO JUSTIFY AN INDUSTRIAL ROBOT INSTALLATION, CONTINUED APPLICATION EVALUATION IS WORTHLESS.

THE WIDE SOCIO-ECOMONIC IMPACTS OF THE APPLICATION OF INDUSTRIAL ROBOTS EXPECTED BY INDUSTRY HAS BEGUN TO BE EVIDENT.

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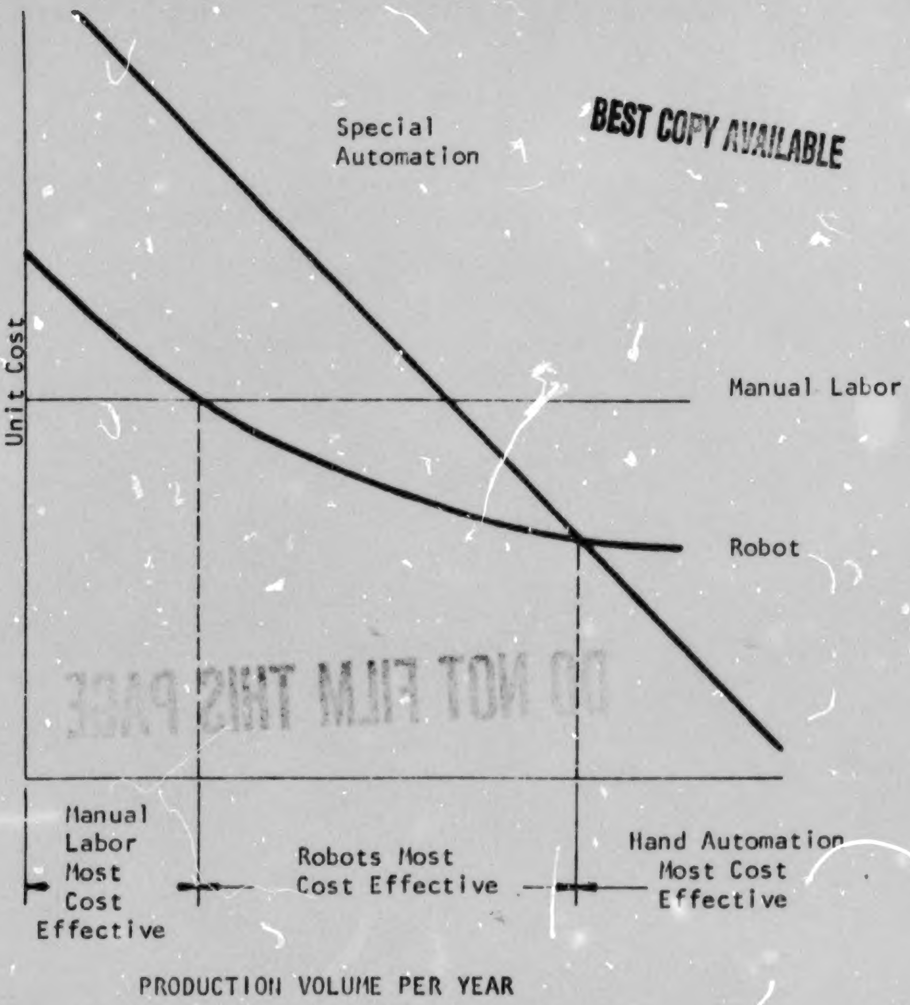

Fig. 2-2 A comparison of unit costs for manufacturing methods by level of production.

1. IMPROVEMENT OF PRODUCTIVITY OF SMALL-BATCH AND MULTI-PRODUCT MIXED-FLOW LINE PRODUCTION SAVED MAN-HOURS AND REDUCED IN-PROCESS AND ACCUMULATED INVENTORY. THE IMPROVED OPERATING RATIO AND INCREASED OPERATING TIME ALSO REDUCED MAN-HOURS. THE RELATIVE EASE WITH WHICH AN INDUSTRIAL ROBOT COULD BE FIT FOR A PRODUCT DESIGN CHANGED SAVED THE TIME USUALLY REQUIRED FOR RETOOLING. THE MORE EFFECTIVE USE OF THE CONVEYOR SYSTEM MADE POSSIBLE BY THE INDUSTRIAL ROBOT ALSO CONTRIBUTED TO ENHANCED PRODUCTIVITY.

2. STABILITY AND IMPROVEMENT IN PRODUCT QUALITY: THE SUPERHUMAN INSTRUCTION LED TO A UNIFORMITY OF PRODUCTS AND HENCE MADE POSSIBLE THE STABILITY AND IMPROVEMENT OF PRODUCT QUALITY. BY WORKING 24 HOURS THE INDUSTRIAL ROBOT ELIMINATED THE INCIDENCE OF INFERIOR OF DEFECTIVE PRODUCTS WHICH OFTEN OCCUR DURING FACTORY

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START-UP OPERATION. THE QUALITY VARIATION WHICH RESULT FROM LONG HOURS OR THE DIFFERING ABILITIES OF OPERATORS WERE ELIMINATED.

3. IMPROVEMENT IN PRODUCTION MANAGEMENT: PRODUCTION MANAGEMENT HAS IMPROVED FOR SEVERAL REASONS: A. REDUCTION OF INVENTORY AND IN-PROCESS PRODUCTS AS A RESULT OF AUTOMATION OF SMALL-BATCH AND MULTI-PRODUCT MIXED-FLOW-LINE-PRODUCTION. B. REDUCTION IN SET-UP TIME AND ELIMINATION OF RETOOLING THE PRODUCTION LINE. C. THE DURABILITY AND ACCURACY OF INDUSTRIAL ROBOTS FACILITATED PRODUCTION PLANNING. D. INDUSTRIAL ROBOTS REACTING MORE ELASTICALLY TO PRODUCTION VOLUME CHANGE REDUCED PROBLEMS OF MANPOWER REALLOCATION. E. INDUSTRIAL ROBOTS HAVE HELPED TO IMPROVE THE QUALITY OF WORK LIFE AND LED TO GREATER EMPLOYMENT STABILITY. IN ADDITION, THEY HAVE CONTRIBUTED TO OVERCOMING THE SKILLED MANPOWER SHORTAGE IN SUCH AREAS AS WELDING AND PAINTING.

4. HUMANIZATION OF WORKING LIFE: A. INDUSTRIAL ROBOTS RELEASED HUMANS FROM HAZARDOUS AND UNHEALTHY WORKING CONDITIONS PREVENTING ACCIDENTS AND OCCUPATIONAL DISEASES. B. INDUSTRIAL ROBOTS RELEASED HUMANS FROM MONOTONOUS WORK AND THUS REDUCED PSYCHOLOGICAL STRESS. C. THE MAN-ROPOT-MACHINE PRODUCTION SYSTEM ELIMINATED THE PSYCHOLOGICAL RESISTANCE TO THE CONVEYOR SYSTEM, AND IMPROVED LABOR QUALITY AND HUMAN SATISFACTION FROM THE HUMAN CONTROL OF ROBOTS. SUCH A SYSTEM CORRESPONDED BETTER TO A MORE HIGHLY EDUCATED AND AGING SOCIETY. HUMAN RESOURCES LIBERATED FROM ADVERSE WORK ENVIRONMENTS AND FROM MONOTONOUS REPETITIVE MANUAL JOBS ARE RECHANNELED INTO MORE INTELLECTUALLY DEMANDING ROBOT OPERATIONS AND MAINTENANCE POSITIONS. FOR EXAMPLE, MANUAL WIRE BONDING OF IC's REQUIRES THE FATIGUING PERFORMANCE OF MONOTONOUS, REPETITIVE TASKS UNDER A MICROSCOPE, AND A TRAINING PERIOD OF 4-5 MONTHS. THE INDUSTRIAL ROBOT REDUCES THE TRAINING PERIOD TO 15 MINUTES AND ELIMINATES THE FATIGUING MANUAL OPERATION.

ROBOT UTILIZATION MAKES POSSIBLE GREATER EMPLOYMENT OPPORTUNITY FOR THE INFIRM, ELDERLY AND FEMALE WORK FORCE IN INDUSTRIES WHERE HEAVY AMD CONTINUOUS LOADING/UNLOADING OR CARRYING A HEAVY WELDING GUN WERE REQUIRED. THE "HUMANIZATION" OR WORK LIFE CONTRIBUTED TO EMPLOYMENT STABILITY, REDUCING ABSENCES FROM WORK.

5. RESOURCE CONSERVATION: INDUSTRIAL ROBOTS CONTRIBUTED TO CONSERVATION OF RESOURCES, A HIGH PRIORITY FACTOR ESPECIALLY SINCE THE OIL CRISIS OF 1973. THESE SAVINGS WERE ACHIEVED IN A VARIETY OF WAYS: A. THE ROBOT SAVED MATERIAL-THE PAINT SPRAYING ROBOT, FOR EXAMPLE, USED 20-30% LESS THAN THE MANUAL PAINTERS IN MANY OPERATIONS. B. THE EASE OF ACCOMMODATING THE ROBOT TO PRODUCT DESIGN CHANGES REDUCED INVESTMENT IN PURCHASING AND/OR REBUILDING EQUIPMENT. C. THE REDUCED DEFECTIVE RATIO SAVED RESOURCES. D. THE INDUSTRIAL ROBOT, BY WORKING IN AN UNPLEASANT ENVIRONMENT, REDUCED THE ENERGY CONSUMPTION OF AIR CONDITIONING, VENTILATION, LIGHTING, ETC.

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ROBOT COST vs. HUMAN COST

THE TREND OF INCREASED PAYMENTS TO WORKERS CONTINUES, SO THAT LABOR WHICH WAS ONCE REGARDED AS CHEAP NOW HAS TO BE PAID AT RATES WHICH COMPENSATE FOR THE MONOTONY AND UNPLEASANT NATURE OF THE JOB. MANY THINGS HAVE CHANGED A QUARTER OF A CENTURY LATER, THE DEMAND FOR SEMI-SKILLED LABOR HAD INCREASED. A SEMI-SKILLED FACTORY LABORER IN THE USA WAS COSTING $6,000 A YEAR IN PAY AND FRINGE BENEFITS. IN THE AUTOMOTIVE INDUSTRY, THIS COST WILL BE DESTINED TO RISE TO CERTAIN LEVELS, (SEE FIGURE 2-3.)

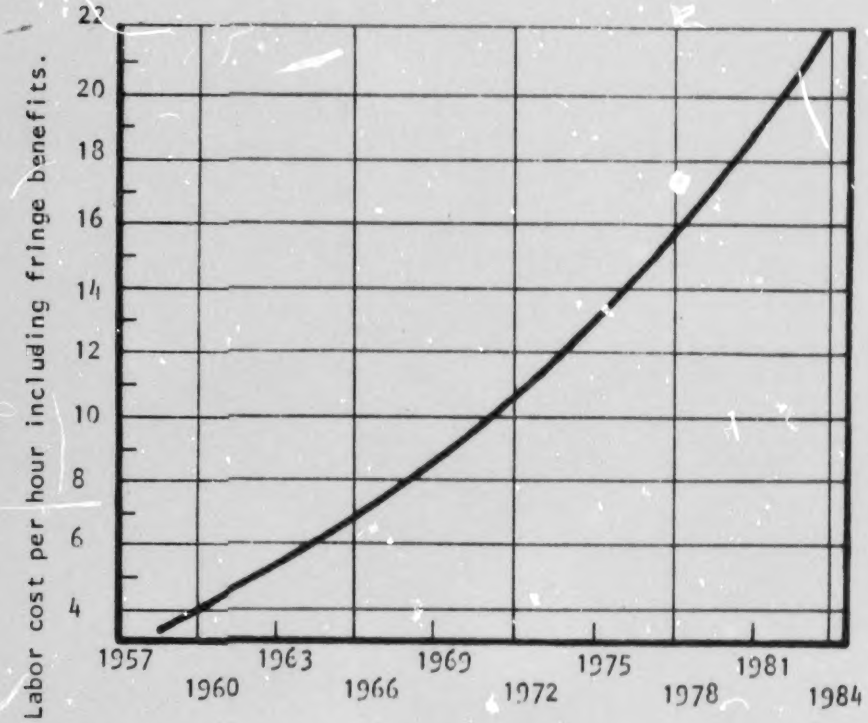

Fig. 2-3. Labor cost escalation in the automotive industry.

TO COMPARE THESE HUMAN COSTS WITH A ROBOT'S, IT IS EASY TO KNOW THAT THE INITIAL COST OF A ROBOT'S INSTALLATION IS CONSIDERABLY HIGHER THAN THAT OF HIRING A NEW EMPLOYEE, THAT DIFFERENTIAL IS MORE THAN THE OFFSET BY THE AVERAGE COST OF A ROBOT'S OPERATION AS COMPARED TO THE AVERAGE REMUNERATION OF A HUMAN WORKER.

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FOR EXAMPLE, LABOR COSTS WERE ABOUT $4.00 PER HOUR IN THE MID 60's, AND INCREASED TO ABOUT $20 PER HOUR IN 1982. BY COMPARISON, THE AVERAGE COST OF OPERATING AN INDUSTRIAL ROBOT IS ABOUT $5.50 AN HOUR AND ITS COST DOES NOT INCREASE OVER TIME AS DO THOSE OF LABOR. (SEE FIGURE 2-4). IN ADDITION, EMPLOYEES MUST UNDERGO CONSIDERABLE RETRAINING WHEN SWITCHED FROM ONE JOB TO ANOTHER, WHILE ROBOTS CAN BE REPROGRAMMED WITH LITTLE DIFFICULTY TO ACCOMMODATE PRODUCTION LINE CHANGE. BESIDES THAT, NON-ECONOMIC FACTORS SUCH AS WORKER SAFETY AND HAZARDOUS CONDITIONS ARE OFTEN CITED AS THE MAIN REASONS FOR ADAPTING A ROBOT SYSTEM; HOWEVER, A COST JUSTIFICATION IS STILL REQUIRED. NOW, LET US CONSIDER THE COST JUSTIFICATION OF A ROBOT INSTALLATION IN USING THREE FINANCIAL ANALYSIS METHODS: 1. PAYBACK PERIOD; 2. RETURN ON INVESTMENT; 3. INTERNAL RATE OF RETURN.

TIME	HUMAN LABOR	ROBOT
Mid 60's	≅4.00	≅4.00
1980	≥16.70	<4.80
1982	≥20.00	<5.50

Fig. 2-4. Human cost vs. robot cost. Unit = $/hour.

TO INTERPRET THESE THREE METHODS, LET US USE THE FOLLOWING DATA OF A TYPICAL ROBOT FOR AN EXAMPLE:

COSTS AND SAVINGS OF A TYPICAL ROBOT INSTALLATION

	Data	Value ($)
COSTS	Purchase Price	P=60,000
	Assessories & Equipment	A=30,000
	Engineering & Installation	I=20,000
	Maintenance & Operation	O=2/hr.
SAVINGS	Direct & Indirect Labor	L=20/hr.
	Material	M=1/hr.
	Tax Credit (10%)	C= 6,000
	Annual Depreciation	D=10.000

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1. PAY BACK PERIOD: THE PAYBACK PERIOD IS A MEASURE OF THE TIME REQUIRED TO RECOVER THE INITIAL INVESTMENTS. A SIMPLE EQUATION FOR DETERMINING PAYBACK PERIOD IS AS FOLLOWS:

$$P6 = \frac{(P+A+I)-C}{(L+M-O)\times H\times(1-TR)+D\times TR}$$

WHERE: P6 = PAYBACK PERIOD
H = HOURS OF USE DURING THE YEAR
TR = THE TAX RATE OF THE FIRM

ASSUME: H = 250 (DAYS) x 8(HOURS) = 2000 HOURS
TR = .40

THEN, IN THIS TYPICAL EXAMPLE, WE HAVE:

$$P6 = \frac{60{,}000+30{,}000+20{,}000-6{,}000}{(20+1-2) \times 2{,}000 \times (1-.4)+10{,}000 \times .4}$$

$$= \frac{104{,}000}{26{,}800} = 3.88 \text{ (YEARS)}$$

IF THE SAME SYSTEM WERE USED ON TWO SHIFTS, THEN H = 4,000 HOURS, AND WE HAVE:

$$P6 = \frac{104{,}000}{19 \times 4{,}000 \times .6 + 4{,}000}$$

$$= \frac{104{,}000}{49{,}600} = 2.10 \text{ (YEARS)}$$

2. RETURN ON INVESTMENT: ONCE A FIRM HAS ASCERTAINED ITS COST OF CAPITAL FOR ITS NEW INVESTMENT IT CAN THEN COMPARE THE RETURN ON INVESTMENT WITH ITS COST OF CAPITAL AND DETERMINE IF IT MEETS OR EXCEEDS THE COST. THE RETURN ON INVESTMENT IS CALCULATED AS FOLLOWS:

$$IR = \frac{S \times 100}{T} \text{ PERCENT}$$

WHERE:

IR = RETURN ON INVESTMENTS
S = TOTAL ANNUAL SAVINGS
= (L+M+O) x H-D
T = TOTAL INVESTMENT
= P+A+I-C

FOR THE TYPICAL COSTS CONSIDERED PREVIOUSLY AND A TWO-SHIFT OPERATION WE HAVE:

$$\begin{aligned} S &= 19 \times 4{,}000-10{,}000 \\ &= 64{,}000 \end{aligned}$$

AND;

$$T = 104{,}000$$

THEN;

$$IR = \frac{64{,}000}{104{,}000} = 61.5\%$$

THIS COMPARES FAVORABLY WITH THE CURRENT COST OF CAPITAL, WHICH MAY BE ASSUMED TO BE 20%, AND DEMONSTRATES THE FAVORABLE RESULTS OF THE ROBOT INSTALLATION. THIS CALCULATION DOES NOT ACCOUNT FOR ANY TAX CONSEQUENCES.

3. INTERNAL RATE OF RETURN: THE CALCULATION OF THE INTERNAL RATE OF RETURN (IRR) UTILIZES A CALCULATION THAT ACCOUNTS FOR THE TIME VALUE OF SAVINGS REALIZED IN THE FUTURE. IN THE EXAMPLE UNDER CONSIDERATION, THE TOTAL INITIAL EXPENDITURE (T) IS $104,000 FOR THE ROBOT AND ASSOCIATED EQUIPMENT. THE ANNUAL SAVINGS ARE EXPERIENCED OVER A SPAN OF SIX YEARS, ASSUMING THE SYSTEM IS RUN FOR TWO SHIFTS, THE ANNUAL SAVINGS (AS) ARE:

$$\begin{aligned} AS &= \left[(L+M-O) \times H-D\right] \times TR \\ &= \left[76{,}000-10{,}000\right] \times 0.4 \\ &= 26{,}400\text{--------(ASSUME } TR = .4) \end{aligned}$$

WHERE AS = THE ANNUAL SAVINGS RECEIVED FOR N YEARS. WHEN THE PRESENT VALUE (PV) IS EQUAL TO THE TOTAL INITIAL INVESTMENTS (T) OF $104,000, THEN THE RATE (R) IS CALLED THE INTERNAL RATE RETURN. CALCULATING THE IRR FOR THE EXAMPLE MAY ACHIEVE USING A TABLE OF DISCOUNT FACTORS OR BY MEANS OF A CALCULATOR OR A COMPUTER. FOR THIS CASE WE HAVE:

$$IRR = 15.1\%$$

4. TOTAL COST COMPARISONS: IT MAY BE USEFUL FOR A FIRM TO COMPARE THE TOTAL COSTS OF USING A ROBOT SYSTEM WITH THAT OF THE NORMAL LABOR PROCEDURE OVER A SELECTED PERIOD, PERHAPS THE LIFE OF THE ROBOT SYSTEM OR THE PLANNING HORIZON OF THE FIRM. WE WILL CONSIDER THE EXAMPLE DISCUSSED BEFORE AND ASSUME A COMPARISON PERIOD (Y) OF FIVE YEARS WITH TWO-SHIFT OPERATION. FOR THE NORMAL LABOR PROCEDURE THE TOTAL COST (TCL) IS:

$$\begin{aligned} TCL &= H \times L \times Y \\ &= 4{,}000\ (\text{HR}) \times 20(\$) \times 5 \\ &= \$400{,}000 \end{aligned}$$

THE TOTAL COST OF THE ROBOT SYSTEM (TCR) MAY BE CALCULATED AS:

$$TCR = (P+A+1-C) + \left[(O-M) \times H-D \times TR\right] \times Y$$

THEN FOR THE EXAMPLE WE HAVE:

$$\begin{aligned} TCR &= 106{,}000+ \left[1 \times 4{,}000-10{,}000 \times 0.4\right] \times 5 \\ &= \$106{,}000 \end{aligned}$$

THEREFORE, OVER THE SELECTED FIVE YEAR PERIOD THE TOTAL COST OF THE LABOR SYSTEM IS ALMOST FOUR TIMES THAT OF THE ROBOT SYSTEM. OF COURSE, THIS FAVORABLE RATIO WOULD DETERIORATE IF MAINTENANCE AND OPERATING COSTS WERE TO INCREASE OVER TIME. AGAIN, A RELIABLE, EASY-TO-MAINTAIN SYSTEM IS CRITICAL TO DESIRABLE FINANCIAL RESULTS.

UNIT 1--INTRODUCTION TO ROBOTS

ASSIGNMENT SHEET 1

AFTER READING THE INFORMATION SHEETS (IS1-2-1, THROUGH (IS1-2-5) PROVIDED, COMPLETE THE FOLLOWING QUESTIONS IN WRITING OR AS REQUESTED BY YOUR INSTRUCTOR.

1. WHAT ARE THE MAJOR CHARACTERISTICS OF INDUSTRIAL ROBOTS IN DETERMINING SOCIO-ECONOMIC IMPACT?

2. WHAT ARE THE CONSIDERATIONS IN USING THE INDUSTRIAL ROBOTS?

3. DRAW A DIAGRAM TO SHOW THE MOST EFFECTIVE QUANTITY OF PRODUCTION IN USING ROBOTS.

4. EVEN THOUGH THE INITIAL COSTS OF ROBOTS ARE CONSIDERABLY HIGHER THAN THE HUMAN LABOR COSTS, WHY ARE INDUSTRIES STILL EXPECTED TO USE ROBOTS IN THEIR FACTORY?

5. THE COSTS AND SAVINGS OF A TYPICAL ROBOT INSTALLATION ARE AS FOLLOWS: CALCULATE THE PAYBACK PERIODS AND THE TOTAL COST COMPARISONS.

PURCHASE PRICE, P=$50,000
ACCESSORIES AND EQUIPMENT, A=$20,000
ENGINEERING & INSTALLATION, I=$18,000
MAINTENANCE & OPERATION, O=$2/HR.
DIRECT & INDIRECT LABOR, L=$20/HR.
MATERIAL, M=$1/HR.
TAX CREDIT, C=$5,000
ANNUAL DEPRECIATION, D=$8,000, (6 YEARS LIFE)

SYLLABUS SHEET FOR LESSON 3
ROBOT SERVICE AND REPAIR

UNIT #1 INTRODUCTION TO ROBOT

DEFINITION AND TERMINOLOGY OF ROBOTS

LESSON OBJECTIVE--UPON COMPLETION OF THIS LESSON, THE STUDENT SHOULD BE ABLE TO:

1. VERBALLY DESCRIBE THE ROBOTIC DEFINITIONS IN RIA AND JIRA.
2. VERBALLY EXPLAIN THE TERMS WHICH WILL BE USED IN THIS COURSE.

TEACHING AIDS:

1. H1-3-1 SYLLABUS SHEET
2. T1-3-1 DEFINITION OF ROBOTS: WEBSTER'S SEVENTH NEW COLLEGIATE DICTIONARY
3. T1-3-2 DEFINITION OF ROBOTS: RIA
4. T1-3-3 DEFINITION OF ROBOTS: JIRA
5. T1-3-4 FIVE AXES ROBOTS

INFORMATIONAL ASSIGNMENTS:

1. IS1-3-1 DEFINITION OF ROBOTS
2. IS1-3-2 TERMINOLOGY OF ROBOTS
   ANSWER QUESTIONS FOUND ON ASSIGNMENT SHEET
1. AS1-3-1 DEFINITION AND TERMINOLOGY OF ROBOTS

REFERENCES:

CONDON, MARY, STRAIGHT TALK ABOUT ROBOTS, TRAINING AND DEVELOPMENT JOURNAL, NOV. 1983, PP. 15-24.

DORF, RICHARD C., ROBOTICS AND AUTOMATED MANUFACTURING, RESTON PUBLISHING COMPANY, INC. RESTON, VIRGINIA, 1983.

STEP 1-INTRODUCTION FOR PREPARATION OF THE STUDENT:

IT IS DIFFICULT TO ESTABLISH A USABLE, GENERALLY AGREED ON DEFINITION OF A ROBOT. EXPERTS USE DIFFERENT APPROACHES TO DEFINING THE TERM. IN ORDER TO DEFINE THE STATE OF THE ART, TO PROJECT FUTURE CAPABILITIES, AND TO COMPARE EFFORTS BETWEEN COUNTRIES, IT IS IMPORTANT TO HAVE SOME COMMON UNDERSTANDING OF THE TERMS IN THE INDUSTRIAL ROBOTS AREA.

IN THIS LESSON, THE STUDENT WILL BE FAMILIAR WITH RIA, JIRA DEFINITIONS OF ROBOTS AND UNDERSTAND THE BASIC TERMS OF INDUSTRIAL ROBOTS.

LESSON SUMMARY AND REVIEW:

1. WHAT DO RIA AND JIRA MEAN?

2. ACCORDING TO JIRA, HOW MANY KINDS OF ROBOTS HAVE THEY DEFINED?

3. WHAT IS MEANT BY DEGREE OF FREEDOM?

4. WHAT DOES THE END EFFECTOR MEAN?

5. HOW MANY KINDS OF ENERGY DO WE USE FOR ROBOTICS POWER SUPPLY?

DEFINITION OF ROBOT

ACCORDING TO WEBSTER'S SEVENTH NEW COLLEGIATE DICTIONARY, THE ROBOT IS DEFINED AS "AN AUTOMATIC APPARATUS OR DEVICE THAT PERFORMS FUNCTIONS ORDINARILY ASCRIBED TO HUMAN BEINGS OR OPERATES WITH WHAT APPEARS TO BE ALMOST HUMAN INTELLIGENCE."

ACCORDING TO THE ELECTRIC MACHINERY LAW OF 1971, JAPAN DEFINED AN INDUSTRIAL ROBOT AS AN ALL PURPOSE MACHINE, EQUIPPED WITH A MEMORY DEVICE, AND A TERMINAL DEVICE (FOR HOLDING THINGS) AND CAPABLE OF ROTATION AND OF REPLACING HUMAN LABOR BY AUTOMATIC PERFORMANCE OF MOVEMENTS. BUT JIRA (JAPAN INDUSTRIAL ROBOT INDUSTRY ASSOCIATION) CLASSIFIES INDUSTRIAL ROBOTS BY THE METHOD OF INPUT INFORMATION AND TEACHING AS FOLLOWS:

1. MANUAL MANIPULATOR- A MANIPULATOR THAT IS WORKED BY AN OPERATOR.
2. FIXED SEQUENCE ROBOT- A MANIPULATOR WHICH REPETITIVELY PERFORMS SUCCESSIVE STEPS OF A GIVEN OPERATION ACCORDING TO A PREDETERMINED SEQUENCE, CONDITION, AND POSITION, AND WHOSE SET INFORMATION CANNOT BE EASILY CHANGED.
3. VARIABLE SEQUENCE ROBOT- A MANIPULATOR WHICH REPETITIVELY PERFORMS SUCCESSIVE STEPS OF A GIVEN OPERATION ACCORDING TO A PREDETERMINED SEQUENCE, CONDITION, AND POSITION, AND WHOSE SET INFORMATION CAN BE EASILY CHANGED.
4. PLAYBACK ROBOT- A MANIPULATOR WHICH CAN PRODUCE, FROM MEMORY, OPERATIONS ORIGINALLY EXECUTED UNDER HUMAN CONTROL. A HUMAN OPERATOR INITIALLY OPERATES THE ROBOT IN ORDER TO INPUT INSTRUCTIONS. ALL THE INFORMATION RELEVANT TO THE OPERATIONS (SEQUENCE, CONDITIONS, AND POSITIONS) IS PUT IN MEMORY. WHEN NEEDED, THIS INFORMATION IS RECALLED (OR PLAYED BACK, HENCE; THE TERM "PLAYBACK" ROBOT) AND THE OPERATIONS ARE REPETITIVELY AND AUTOMATICALLY EXECUTED FROM MEMORY.

5. NUMERICAL CONTROL (NC) ROBOT- A MANIPULATOR THAT CAN PERFORM A GIVEN TASK ACCORDING TO THE SEQUENCE, CONDITIONS AND POSITION, AS COMMANDED VIA NUMERICAL DATA. THE SOFTWARE USED FOR THESE ROBOTS INCLUDES PUNCHED TAPES, CARDS, AND DIGITAL SWITCHES. THIS ROBOT HAS THE SAME CONTROL MODE AS AN NC MACHINE.
6. INTELLIGENT ROBOT- THIS ROBOT USES SENSORY PERCEPTION (VISUAL AND/OR TACTILE) TO INDEPENDENTLY DETECT CHANGES IN THE WORK ENVIRONMENT OR WORK CONDITION AND, BY ITS OWN DECISION-MAKING FACULTY, PROCEED WITH ITS OPERATION ACCORDINGLY (ENGELBERGER, 1980).

IN THIS CURRICULUM PACKAGE I HAVE USED THREE DIFFERENT ROBOT DEFINITIONS:

1. ROBOTS BY JAPANESE DEFINITION - ALL 6 CLASSES.
2. ROBOTS BY U.S. DEFINITION - CLASSES 3, 4, 5, AND 6
3. SOPHISTICATED ROBOT - CLASSES 4, 5, AND 6.

THE ROBOT INSTITUTE OF AMERICA (RIA) DEFINES A ROBOT AS "A ROBOT IS A PROGRAMMABLE, MULTIFUNCTIONAL MANIPULATOR DESIGNED TO MOVE MATERIAL, PARTS, TOOLS, OR SPECIALIZED DEVICES, THROUGH VARIABLE PROGRAMMED MOTIONS FOR THE PERFORMANCE OF A VARIETY OF TASKS".

ONE FEATURE WHICH A DEVICE MUST POSSESS IF IT IS TO RANK AS A ROBOT, IS THE ABILITY TO OPERATE AUTOMATICALLY, ON ITS OWN. THIS MEANS THAT THERE MUST BE INBUILT INTELLIGENCE, OR A PROGRAMMABLE MEMORY, OR SIMPLY AN ARRANGEMENT OF ADJUSTABLE MECHANISMS THAT COMMAND MANIPULATION.

ROBOTS ARE GENERALLY SEEN AS ANTHROPOMORPHIC COPIES OF HUMANS, COMBINING HUMAN QUALITIES OF INTELLIGENCE, MOBILITY, AND MANIPULATION ABILITY. THE ROBOT'S END EFFECTOR OR "HAND"-- IT MAY BE A SPRAY PAINTER, SCREWDRIVER, WELDER, OR GRIPPER--EQUATES TO A TOOL IN THE HAND OF A HUMAN. DEPENDING ON THE INTELLIGENCE THAT IS PROVIDED WITHIN THE COMPUTER CONTROLLER AND ITS COMPUTER, IT CAN BE A HIGHLY SOPHISTICATED ROBOT FITTING IN CLASSIFICATION 6.

DEFINITION OF ROBOT (CONTINUED)

IN A TECHNICAL SENSE, INDUSTRIAL ROBOTS ARE UNIVERSALLY APPLICABLE KINETIC MACHINES WHICH, IN CONTRAST TO CONVENTIONAL MACHINES, CAN CARRY OUT RELATIVELY COMPLICATED SERIES OF MOVEMENTS.

TERMINOLOGY OF ROBOT

THERE ARE THREE GENERAL AREAS OF ROBOTS: THE MECHANICAL UNIT, POWER SUPPLY AND CONTROLLER. BEFORE WE GET INTO EACH OF THEM, WE HAVE TO FAMILIARIZE WITH SOME COMMON TERMS AS FOLLOWS:

1. AXES: THE AXES ARE ALSO KNOWN AS "DEGREE OF FREEDOM". THE NUMBER OF INTRICATE MOTIONS A ROBOT CAN PERFORM IS DETERMINED BY THE NUMBER OF AXES THE ROBOT HAS.

FIG. 1-3-1 SHOWS THE TYPICAL DEGREE OF FREEDOM MOST COMMONLY USED. THE COMPLEXITY OF THE TASK A ROBOT CAN PERFORM IS DETERMINED BY THE NUMBER OF AXES THE ROBOT HAS.

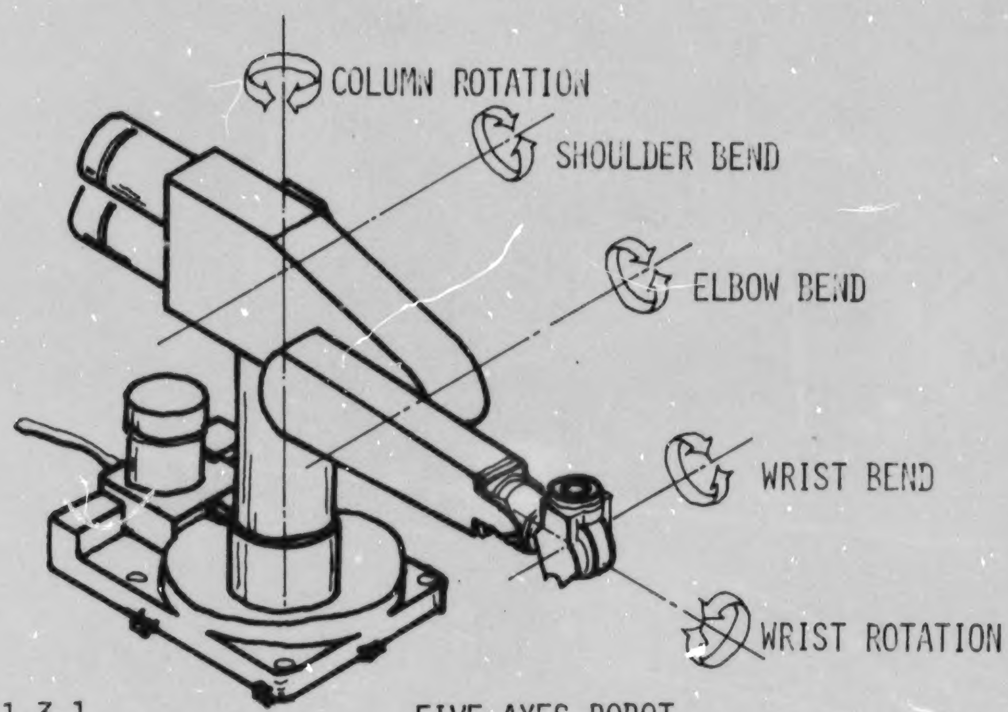
COLUMN ROTATION
SHOULDER BEND
ELBOW BEND
WRIST BEND
WRIST ROTATION

FIG. 1-3-1 FIVE AXES ROBOT

TERMINOLOGY OF ROBOT (CONTINUED)

A ROBOT USED FOR SIMPLE TRANSFER OPERATIONS AS SHOWN IN FIG. 1-3-2, MAY REQUIRE ONLY 2 AXES, SUCH AS COLUMN ROTATE AND EXTEND/RETRACT. FIG. 1-3-3, DEPICTS A ROBOT THAT HAS THE CAPABILITY TO FOLLOW AN AUTOMOBILE DOWN AN ASSEMBLY LINE, REACH INSIDE OF THE AUTOMOBILE TO WELD SOME RECESSED POINT, AND RETURN TO ITS WORK STATION TO AWAIT THE ARRIVAL OF THE NEXT AUTOMOBILE. A ROBOT WITH ALL THIS CAPABILITY MAY REQUIRE UP TO TEN AXES OF MOTION. GENERALLY, MOST INDUSTRIAL ROBOT APPLICATIONS REQUIRE ONLY THREE TO GIVE DEGREE OF FREEDOM TO PERFORM A SPECIFIC TASK.

FIG. 1-3-2 TWO AXES OF MOTION

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TERMINOLOGY OF ROBOT (CONTINUED)

FIG. 1-3-3 TEN AXES OF MOTION

2. MANIPULATOR- A SYSTEM OF MECHANICAL LINKAGES AND JOINTS THAT CAN BE MOVED IN VARIOUS DIRECTIONS TO PERFORM THE WORK OF THE ROBOT. IN SOME INSTANCES THE MANIPULATOR IS ALSO CALLED THE ROBOT ARM.

3. ACTUATOR- ACTUATORS ARE THE DRIVE MECHANISMS THAT POSITION THE MANIPULATOR TO A PREDETERMINED POINT. THE ACTUATOR CAN BE:
   --PNEUMATIC CYLINDERS
   --HYDRAULIC CYLINDERS
   --PNEUMATIC MOTORS
   --HYDRAULIC MOTORS
   --ELECTRIC MOTORS
   SPECIFIC ACTUATORS AND METHODS OF CONTROLLING THEM WILL BE COVERED IN DETAIL IN UNIT TWO.

GRIPPER:

A HAND-LIKE DEVICE SOMETIMES REFERRED TO AS THE "END EFFECTOR". IT HOLDS THE TOOL DOING THE WORK OR HANDLES THE MATERIAL BEING PROCESSED. MOST GRIPPERS ARE SIMPLE OPEN/CLOSE DEVICES THAT ARE ACTUATED HYDRAULICALLY, PNEUMATICALLY, MECHANICALLY, OR WITH ELECTRIC MOTORS. THE VARIETY OF GRIPPERS THAT CAN BE ADAPTED FOR ROBOT USE IS VIRTUALLY UNLIMITED. THE DETAILED CONFIGURATION AND ITS USAGE WILL BE COVERED IN DETAIL IN LESSON PLAN NUMBER FIVE.

CONTROLLER:

THE CONTROLLER IS THE BRAINS AND NERVOUS SYSTEM OF THE ROBOT WHOSE INPUT ARE BOTH THE DESIRED AND MEASURED POSITION VELOCITY OR OTHER PERTINENT VARIABLES IN A PROCESS, AND WHOSE OUTPUTS ARE DRIVE SIGNALS TO A CONTROLLING MOTOR OR ACTUATOR. THE CONTROLLER HAS A THREEFOLD FUNCTION:

1. TO INITIATE AND TERMINATE MOTIONS OF THE MANIPULATOR.
2. TO STORE POSITION AND SEQUENCE DATA IN MEMORY.
3. TO INTERFACE WITH THE "OUTSIDE WORLD".

A CONTROLLER CAN BE ANY PROGRAMMABLE DEVICE FROM A SIMPLE MECHANICAL ROTARY DRUM SWITCH TO A COMPLEX ELECTRONIC COMPUTER. THE CONTROLLER MAY BE EITHER AN INTEGRAL PART OF THE MANIPULATOR OR HOUSED IN A SEPARATE CABINET.

POWER SUPPLY:

THE FUNCTION OF THE POWER SUPPLY IS TO PROVIDE ENERGY TO THE MANIPULATOR'S ACTUATORS. IN THE CASE OF ELECTRICALLY DRIVEN ROBOTS, THE POWER SUPPLY FUNCTIONS BASICALLY TO REGULATE THE INCOMING ELECTRICAL ENERGY. POWER FOR PNEUMATICALLY ACTUATED ROBOTS IS USUALLY SUPPLIED BY A REMOTE COMPRESSOR, WHICH MAY ALSO SERVICE OTHER EQUIPMENT.

LESSON PLAN #3

UNIT 1 - INTRODUCTION TO ROBOTS

ASSIGNMENT SHEET 1

AFTER READING THE INFORMATION SHEETS (IS1-3-1 AND IS1-3-2) PROVIDED, COMPLETE THE FOLLOWING QUESTIONS IN WRITING OR AS REQUESTED BY YOUR INSTRUCTOR.

1. ACCORDING TO RIA, DEFINE WHAT ARE ROBOTS?

2. EXPLAIN WHAT IS THE DIFFERENCE BETWEEN FIXED SEQUENCE ROBOT AND VARIABLE SEQUENCE ROBOT?

3. WHAT IS INTELLIGENT ROBOT?

4. SIMPLY MAKE A DRAWING TO SHOW A FIVE AXES ROBOT.

5. WHAT IS AN ACTUATOR? HOW MANY KINDS ARE THERE?

SYLLABUS SHEET FOR LESSON 4
ROBOT SERVICE AND REPAIR

UNIT #1 INTRODUCTION TO ROBOTS

ROBOT CLASSIFICATION

LESSON OBJECTIVE--UPON COMPLETION OF THIS LESSON, THE STUDENT SHOULD BE ABLE TO:

1. VERBALLY CLASSIFY THE ROBOTS BY GENERATION, MOTION, CONTROL SYSTEM, DRIVING SYSTEM AND TECHNOLOGY LEVELS.
2. VERBALLY DESCRIBE THE OPERATING SEQUENCE OF THE DIFFERENT CONTROLLED ROBOTS.
3. LIST THE TASKS ASSIGNED IN THE DIFFERENT TECHNOLOGY LEVEL OF A ROBOT.

TEACHING AIDS:

1. H1-4-1 SYLLABUS SHEET
2. T1-4-1 ROBOT CLASSIFIED BY GENERATION
3. T1-4-2 ROBOT CLASSIFIED BY MOTION
4. T1-4-3 OPERATING SEQUENCE OF A NON-SERVO CONTROLLED SYSTEM
5. T1-4-4 OPERATING SEQUENCE OF A SERVO CONTROLLED SYSTEM
6. T1-4-5 DRIVEN SYSTEM

INFORMATIONAL ASSIGNMENTS:

1. IS1-4-1 CLASSIFIED BY GENERATION
2. IS1-4-2 CLASSIFIED BY MOTIONS
3. IS1-4-3 CLASSIFIED BY CONTROL SYSTEMS
4. IS1-4-4 CLASSIFIED BY DRIVING SYSTEMS
5. IS1-4-5 CLASSIFIED BY TECHNOLOGY LEVELS
   ANSWER QUESTIONS FOUND ON THE ABOVE ASSIGNMENT SHEETS
1. AS1-4-1

REFERENCES:

TVER, DAVID F. AND BOLZ, ROGER W.; ROBOTICS SOURCEBOOK AND DICTIONARY, INDUSTRIAL PRESS INC., 1983.

ENGELBERGER, J.F.; ROBOTICS IN PRACTICE, AMERICAN MANAGEMENT ASSOCIATION, NEW YORK, 1980.

STEP 1-INTRODUCTION FOR PREPARATION OF THE STUDENT:

TO UNDERSTAND ROBOTS, YOU NEED TO FAMILIARIZE BETTER WITH ALL OF THE DIFFERENT KINDS OR CATEGORIES OF ROBOTS. FOR EXAMPLE, ROBOT CAPABILITIES RANGE FROM VERY SIMPLE REPETITIVE POINT TO POINT MOTION TO EXTREMELY VERSATILE MOVEMENTS THAT CAN BE CONTROLLED AND SEQUENCED BY A COMPUTER AS A COMPLETE INTEGRATED MANUFACTURING SYSTEM.

IN THIS UNIT, THE STUDENT WILL LEARN AND KNOW THAT THE ROBOTS WILL BE CLASSIFIED BY GENERATIONS, MOTIONS, CONTROL SYSTEMS, DRIVING SYSTEMS AND ITS TECHNOLOGY LEVELS, FROM WHICH THE STUDENT WILL BE ABLE TO KNOW AND CHOOSE SOME APPROPRIATE TYPES AND FUNCTIONS OF ROBOTS FOR USE IN TYPICAL INDUSTRIAL AREAS. THEY WILL ALSO BE INTRODUCED TO ROBOTICS OPERATING SEQUENCE AND RELATED FUNCTIONS.

LESSON SUMMARY AND REVIEW:

1. HOW MANY GENERATIONS OF ROBOTS HAVE WE DISCUSSED AND WHICH GENERATION ARE WE USING IN INDUSTRY TODAY?

2. WHAT IS A "BANG-BANG" ROBOT?

3. DRAW A DIAGRAM TO SHOW THE OPERATING SEQUENCE OF SERVO-CONTROLLED ROBOTS.

4. HOW MANY KINDS OF DRIVING SYSTEMS ARE USED IN ROBOTICS INDUSTRY TODAY?

5. ACCORDING TO THE CLASSIFICATION OF THE TECHNOLOGY LEVEL OF ROBOTS, THE TASK OF SPRAY PAINTING OPERATIONS AND MEASURING INSPECTION BELONG TO WHICH LEVELS?

CLASSIFICATION BY GENERATION

1. GENERATION 1 ROBOT.

THIS IS A KIND OF ROBOT MOSTLY USED TODAY. IT IS CHARACTERIZED AS BEING A PROGRAMMABLE, MEMORY-CONTROLLED MULTIFUNCTION MACHINE WITH SEVERAL DEGREES OF FREEDOM. IT CAN BE EQUIPPED WITH GRIPPERS OF SPECIAL HANDLING ATTACHMENTS, WHICH CAN HOLD AND OPERATE DIFFERENT KINDS OF TOOLS AS WELL AS PERFORM WORKPIECE AND MATERIAL-HANDLING, -MANIPULATING AND -TRANSFER FUNCTIONS.

2. GENERATION 2 ROBOT.

THIS IS THE ROBOT THAT WILL BE SENSORY CONTROLLED AND HAVE CAPABILITIES TO PERFORM, "MAKE", AND "TEST" FUNCTIONS. IT WILL WORK ON PRINCIPLES OF ELECTROOPTICS, PRESSURE, TORQUE, FORCE-SENSITIVE TOUCH, AND PROXIMITY. IT WILL BE CAPABLE OF RECOGNIZING AND MANIPULATING WORKPIECES, PARTS, AND TOOLS. THE MOTION PATHS OF THE ROBOT WILL BE MEMORY CONTROLLED WITH OVERIDES OF PREPROGRAMMED CONTROL, DEPENDING ON SENSOR INPUTS.

3. GENERATION 3 ROBOT.

THIS WILL BE THE FUTURE ROBOT THAT WILL HAVE EYE-AND-HAND COORDINATION CONTROL THROUGH THEIR VISION CONTROL SYSTEM. THE ROBOT WILL SEE OBJECTS AND WILL BE ABLE, WITH HAND INTERACTIONS, TO PERFORM MANIPULATOR FUNCTIONS.

CLASSIFIED BY MOTIONS

1. BANG-BANG ROBOT.

A BANG-BANG ROBOT IS THE SIMPLEST CONTROLLED KIND OF ROBOT, IN WHICH MOTIONS ARE CONTROLLED BY DRIVING EACH AXIS, OR DEGREE OF FREEDOM, AGAINST A MECHANICAL STOP. AS FIXED STOP MACHINES, EACH OF ITS AXES HAS A FIXED LIMIT AT EACH END OF ITS STROKE AND CANNOT STOP EXCEPT AT ONE OR ANOTHER OF THESE LIMITS.

2. POINT TO POINT ROBOT.

THIS KIND OF ROBOT, PERHAPS, IS THE MOST FREQUENTLY USED TODAY. THE MOTION OF THE ROBOT END EFFECTOR IS DONE BY MOVING EACH AXIS OF THE ROBOT INDIVIDUALLY UNTIL THE COMBINATION OF AXIS POSITION YIELDS THE DESIRED POSITION. EACH AXIS RUNS AT ITS MAXIMUM OR LIMITED RATE UNTIL IT REACHES ITS FINAL POSITION. BECAUSE THERE IS NO COORDINATION OF MOTION BETWEEN AXES, THE PATH AND VELOCITY OF THE END EFFECTOR BETWEEN POINTS IS NOT EASILY PREDICTABLE. FOR THIS REASON, THE POINT TO POINT ROBOT IS USED FOR APPLICATIONS WHERE ONLY THE FINAL POSITION IS OF INTEREST AND THE PATH AND VELOCITY BETWEEN THE POINTS ARE NOT IMPORTANT.

--50% OF THE MARKET.

--APPLICATION: PICK AND PLACE
MACHINE LOADING AND UNLOADING
SPOT WELDING
FORGING, AND ETC.

3. CONTINUOUS PATH ROBOT.

THIS ROBOT OPERATES, IN THEORY, THROUGH AN INFINITE NUMBER OF POINTS IN SPACE THAT WHEN JOINED, DESCRIBES A SMOOTH COMPOUND CURVE. THIS CURVE IS USUALLY DEVELOPED DURING THE PROGRAMMING OR "TEACHING" PHASE, WHICH IS CARRIED OUT BY AN OPERATOR.

CONTINUOUS PATH ROBOTS ARE USED WHERE THE PATH OF THE END EFFECTOR IS OF PRIMARY IMPORTANCE TO THE APPLICATION, SUCH AS, WELDING PROCESSES OR SPRAY PAINTING OPERATIONS.

CLASSIFIED BY MOTIONS (CONTINUED)

THE CONTROL OF THIS TYPE OF ROBOT, IS THAT CONSIDERABLE MEMORY CAPABILITY IS REQUIRED TO STORE ALL THE AXIS POSITIONS NEEDED TO RECORD THE DESIRED PATH SMOOTHLY.

--THE ROBOT CAN ALLOW CLOSELY SPACED POINTS.
--GREAT ACCURACY OF ARM MOVEMENT AND LOCATIONS.
--MORE EXPENSIVE.
--APPLICATIONS: SPRAY PAINTING
WELDING
DEBURRING
CUTTING

CLASSIFIED BY CONTROL SYSTEMS

1. NON-SERVO CONTROLLED ROBOTS.

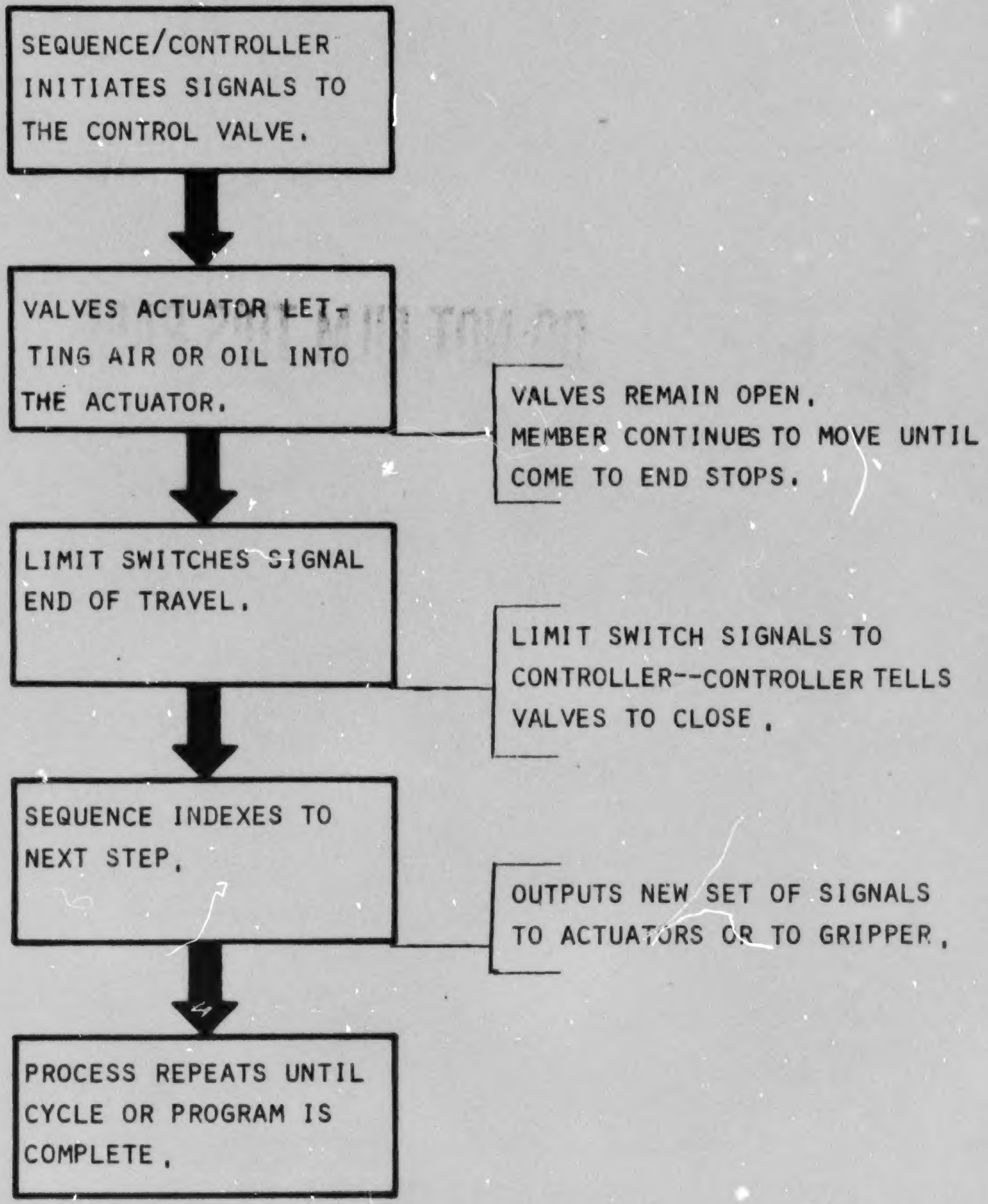
THE NON-SERVO CONTROLLED ROBOTS ARE RESTRICTED TO THREE OR FOUR AXES (DEGREE OF FREEDOM). THESE KINDS OF ROBOTS MOVE ARMS IN OPEN-LOOP FASHION BETWEEN EXACT END POINT LOCATIONS ALONG PREDETERMINED TRAJECTORIES, WITH FIXED SEQUENCES. USUALLY, MECHANICAL STOPS ARE USED ON EACH AXIS TO LIMIT THE AMOUNT OF MOTION. OWING TO THESE KINDS OF ROBOTS ARE GENERALLY SMALLER SIZES OF THE MANIPULATOR AND THE FULL FLOW OF AIR OR OIL THROUGH THE CONTROL VALVES. REPEATABILITY WITHIN 0.010", (0.25 MM.) IS ATTAINABLE ON THE SMALLER UNITS. NON-SERVO CONTROLLED ROBOTS ARE ALSO NAMED "END POINT", "PICK AND PLACE", "BANG-BANG", AND "LIMITED SEQUENCE". THAT MEANS, THEY HAVE LIMITED CAPABILITIES AND RESTRICTED ADAPTABILITIES.

2. COMMON CHARACTERISTICS OF NON-SERVO CONTROLLED ROBOTS.
   - --RELATIVELY HIGH SPEED MOTIONS ARE POSSIBLE.
   - --RELATIVELY LOW COST, SIMPLE TO OPERATE, PROGRAM, AND MAINTAIN.
   - --HIGHLY RELIABLE.
   - --LIMITED PROGRAMMING/POSITIONING FLEXABILITY.

3. FEATURES OF NON-SERVO CONTROLLED ROBOTS.
   - --SEQUENCER PROVIDES THE CAPABILITY FOR MANY MOTIONS IN A PROGRAM, BUT ONLY 2 POSITIONS CAN BE USED IN ANY PROGRAM.
   - --DECELERATION (CUSHIONING) AT STOPS IS AVAILABLE.
   - --INTERMEDIATE STOPS, MORE THAN TWO ADDITIONAL ON SOME AXES ARE PRACTICAL.
   - --CONDITIONAL MODIFICATION TO PROGRAM IS POSSIBLE BUT LIMITED.

CLASSIFIED BY CONTROL SYSTEMS (CONTINUED)

4. OPERATING SEQUENCE OF NON-SERVO CONTROLLED ROBOTS.



SEQUENCE/CONTROLLER INITIATES SIGNALS TO THE CONTROL VALVE.

VALVES ACTUATOR LETTING AIR OR OIL INTO THE ACTUATOR.

VALVES REMAIN OPEN.
MEMBER CONTINUES TO MOVE UNTIL COME TO END STOPS.

LIMIT SWITCHES SIGNAL END OF TRAVEL.

LIMIT SWITCH SIGNALS TO CONTROLLER--CONTROLLER TELLS VALVES TO CLOSE.

SEQUENCE INDEXES TO NEXT STEP.

OUTPUTS NEW SET OF SIGNALS TO ACTUATORS OR TO GRIPPER.

PROCESS REPEATS UNTIL CYCLE OR PROGRAM IS COMPLETE.

CLASSIFIED BY CONTROL SYSTEMS (CONTINUED)

5. SERVO CONTROLLED ROBOTS.

SERVO CONTROLLED ROBOTS, WHOSE AXES OF MOTION ARE CONTROLLED TO MOVE AND TO STOP ANYWHERE WITHIN THEIR LIMITS OF TRAVEL RATHER THAN ONLY AT THE EXTREMES, HAVE TWO TYPES OF SERVO CONTROLLED ROBOTS.

A. POINT TO POINT SERVO CONTROLLED ROBOTS ARE TYPICAL SERVO-CONTROLLED ROBOTS USED IN A WIDE VARIETY OF INDUSTRIAL APPLICATIONS FOR BOTH PART-HANDLING AND TOOL HANDLING TASKS. THESE KINDS OF ROBOTS MOVE BETWEEN PRECISE, PROGRAMMED, AND THREE-DIMENSIONAL POINTS WITHIN ITS WORK ENVELOPE. IN APPLICATION, USUALLY ONLY THE END STOPS ARE TAUGHT AND THE ROBOT TAKES THE FASTEST AND MOST DIRECT ROUTE TO REACH THEM. THESE ROBOTS TEND TO LIE AT THE UPPER END OF THE SCALE IN TERMS OF LOAD CAPACITY AND WORKING RANGE. HYDRAULIC DRIVES ARE THE MOST COMMONLY USED. HOWEVER, SOME ROBOTS ARE AVAILABLE WITH ELECTRIC DRIVES.

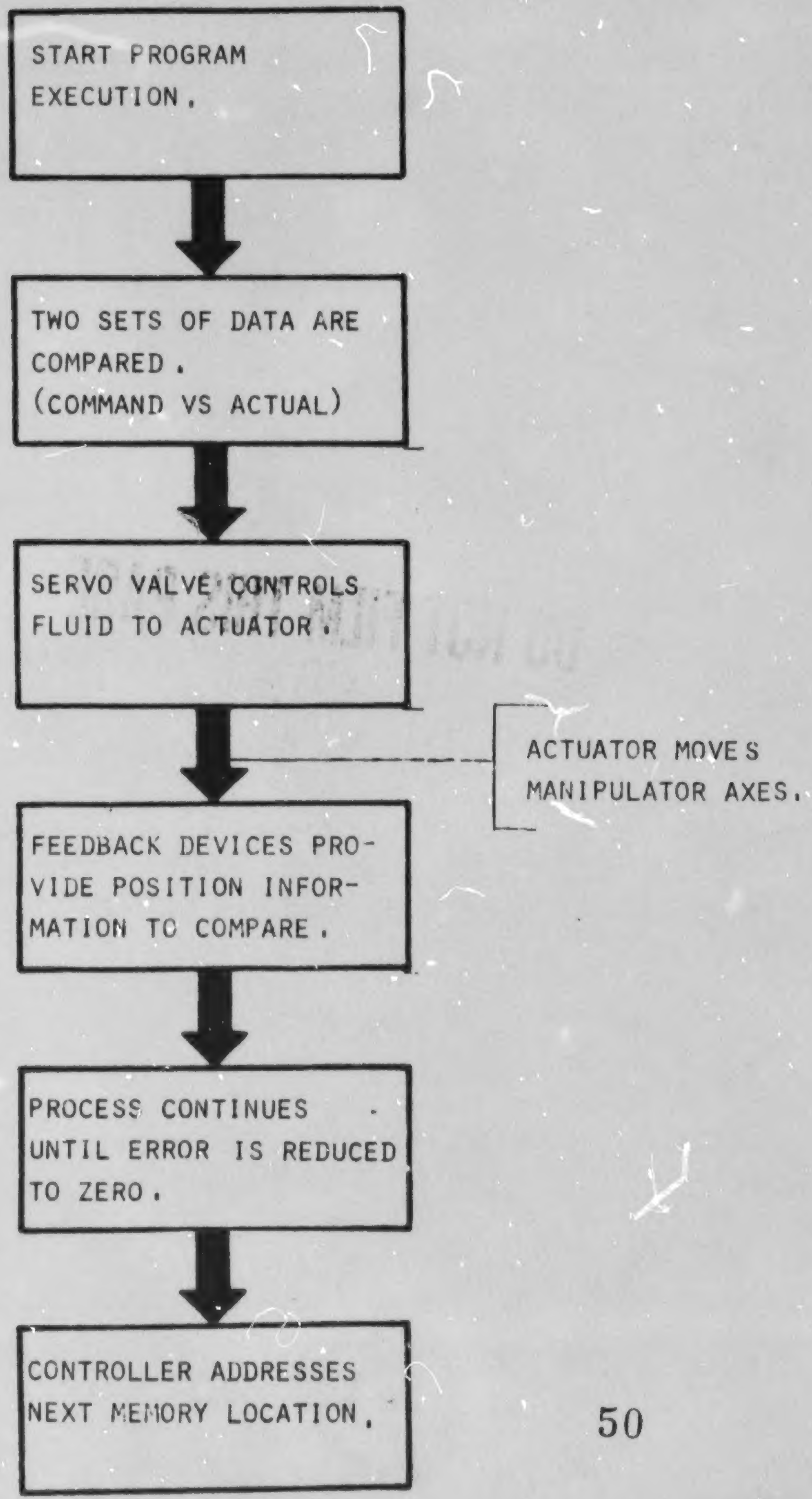
B. CONTINUOUS PATH SERVO CONTROLLED ROBOTS--THESE KINDS OF ROBOTS ARE USUALLY SMOOTH, CONTINUOUS MOTIONS OVER A CONTROL PATH. THE TRAJECTORY OF THE CONTINUOUS PATH ROBOT IS USUALLY A CURVED PATH WITH LITTLE OR NO STOPPING AT PREPROGRAMMED END STOPS. FOR THIS REASON, CONTINUOUS PATH ROBOTS ARE IDEALLY SUITED FOR SPRAY PAINTING AND SIMILAR SPRAYING OPERATIONS, POLISHING, GRINDING, AND ARC WELDING. ONE DRAWBACK TO THE SERVO CONTROLLED CONTINUOUS PATH ROBOTS IS THE LARGE AMOUNT OF CONTROLLER MEMORY REQUIRED. OWING TO GREATER MEMORY, WHICH IS REQUIRED, THE SERVO-CONTROL ROBOTS ARE MORE EXPENSIVE AND MORE INVOLVED TO MAINTAIN THAN NON-SERVO ROBOTS AND TEND TO BE SOMEWHAT LESS RELIABLE.

CLASSIFIED BY CONTROL SYSTEMS (CONTINUED)

6. CHARACTERISTICS OF SERVO CONTROLLED ROBOTS:
   - --SMOOTH MOTION.
   - --FLEXABILITY.
     - MANIPULATOR MEMBER/AXES CAN BE POSITIONED ANYWHERE WITHIN LIMITED SPACE.
   - --MULTIPLE PROGRAM.
     - THE MEMORY CAPACITY IS LARGE ENOUGH TO STORE AS MANY AS 4,000 POINTS IN SPACE.
     - BRANCHING/SUBROUTINE CAPABILITIES MAY ALSO BE AVAILABLE.
     - PROGRAMS CAN BE VARIED TO MAINTAIN THE SCHEME WHILE CHANGING THE ACTIVITY POINTS, (BOTH CONTINUOUS PATH AND POINT TO POINT).
   - --ACCURACY AND REPEATABILITY.
     - END OF ARM POSITIONING ACCURACY/REPEATABILITY 0.050 (1.5 MM)/0.060 (1.5 MM) ARE GENERALLY ACHIEVED.
     - ACCURACY/REPEATABILITY ARE FUNCTIONS OF:
       - MECHANISMS.
       - THE RESOLUTION OF THE FEEDBACK DEVICES.
       - SERVOVALVE CHARACTERISTICS.
       - CONTROLLER ACCURACY.
   - --MORE COMPLEXITY, MORE INVOLVED TO MAINTAIN; HENCE, TEND TO BE LESS RELIABLE.

CLASSIFIED BY CONTROL SYSTEMS (CONTINUED)

7. OPERATING SEQUENCE OF A SERVO CONTROLLED SYSTEM.


START PROGRAM EXECUTION.
TWO SETS OF DATA ARE COMPARED. (COMMAND VS ACTUAL)
SERVO VALVE CONTROLS FLUID TO ACTUATOR.
ACTUATOR MOVES MANIPULATOR AXES.
FEEDBACK DEVICES PROVIDE POSITION INFORMATION TO COMPARE.
PROCESS CONTINUES UNTIL ERROR IS REDUCED TO ZERO.
CONTROLLER ADDRESSES NEXT MEMORY LOCATION.

CLASSIFIED BY DRIVING SYSTEMS

1. DRIVE SYSTEMS.

A DRIVE SYSTEM IS REQUIRED FOR EACH ROBOT ARTICULATION. IN ADDITION TO DRIVING THE ARM, THE HAND, AND THE WRIST; MOST TYPES OF GRIPPERS ALSO NEED A DRIVE MECHANISM FOR THE FUNCTIONS OF HOLDING AND RELEASING.

ROBOT DRIVE SYSTEMS CAN BE ELECTRICAL, PNEUMATIC, HYDRAULIC OR SOME COMBINATION OF THESE.

2. PNEUMATIC SYSTEMS.

PNEUMATIC SYSTEMS ARE FOUND IN ABOUT 30% OF THE ROBOT. (ENGELBERGER, 1980)

PNEUMATIC DRIVES HAVE THE MERIT OF BEING CHEAPER THAN OTHER METHODS, AND THEIR INHERENT RELIABILITY MEANS THAT MAINTENANCE COSTS CAN BE KEPT DOWN.

PNEUMATIC ROBOTS ARE USUALLY DESIGNED FOR NONSOPHISTICATED, HIGH CYCLE RATE OPERATIONS, SUCH AS PICK AND PLACE TASKS.

SINCE MACHINE SHOPS TYPICALLY HAVE COMPRESSED AIR LINES AVAILABLE THROUGHOUT THEIR WORKING AREAS, THIS MAKES THE PNEUMATICALLY DRIVEN ROBOT A MORE FAMILIAR TOOL TO SHOP PERSONNEL. UNFORTUNATELY, THE SYSTEM DOES NOT MAKE FOR EASY CONTROL OF EITHER SPEED OR POSITION, WHICH ARE TWO ESSENTIAL INGREDIENTS FOR ANY SUCCESSFUL ROBOT.

3. ELECTRICAL SYSTEMS.

ELECTRICAL DRIVES ARE USED IN SOME 20% OF THE ROBOTS. (ENGELBERGER, 1980) TYPICAL FORMS ARE SERVOMOTORS, STEPPING MOTORS,PULSE MOTORS, LINEAR SOLENOID AND ROTATIONAL SOLENOIDS.

ELECTRICAL DRIVEN ROBOTS DON'T HAVE THE HIGH STRENGTH AND SPEED OF HYDRAULIC ROBOTS, BUT THEY POSSESS BETTER ACCURACY AND REPEATABILITY WITH LESS FLOOR SPACE REQUIRED.

CLASSIFIED BY DRIVING SYSTEMS (CONTINUED)

4. HYDRAULIC SYSTEMS.

HYDRAULIC DRIVEN SYSTEMS ARE THE MOST POPULAR FORM USED IN ROBOT INDUSTRY TODAY. THEY ARE USUALLY ASSOCIATED WITH LARGE ROBOTS.

THIS TYPE OF SYSTEM GIVES THE ROBOT A MECHANICAL SIMPLICITY, MAINTAINS A HIGH STRENGTH AND SPEED, AND GETS MORE ACCURATE CONTROL.

CLASSIFIED BY TECHNOLOGY LEVELS

THERE ARE THREE CATEGORIES OF INDUSTRIAL ROBOTS CLASSIFIED BY TECHNOLOGY LEVELS. THEY ARE:

--LOW TECHNOLOGY
--MEDIUM TECHNOLOGY AND
--HIGH TECHNOLOGY

EACH CATEGORY OF ROBOT HAS ITS OWN TYPICAL CHARACTERISTICS, SUCH AS:

--NUMBER OF AXES (DEGREE OF FREEDOM)
--TYPES OF CONTROL SYSTEMS
--PROGRAMMING METHODS
--TYPES OF MOTION
--TYPES OF DRIVING SYSTEMS

UNDER THE GENERAL CLASSIFICATION OF INDUSTRIAL ROBOTS, THESE CATEGORIES CAN BE BASED ON THE TYPE OF WORK THE ROBOT IS ASSIGNED TO DO. SEE FIGURE 1-4-1. ( ) DIFFERENT KINDS OF WORK HAVE TO HAVE DIFFERENT TECHNOLOGY LEVELS OF A ROBOT.

CLASSIFIED BY DRIVING SYSTEMS (CONTINUED)

4. HYDRAULIC SYSTEMS.

HYDRAULIC DRIVEN SYSTEMS ARE THE MOST POPULAR FORM USED IN ROBOT INDUSTRY TODAY. THEY ARE USUALLY ASSOCIATED WITH LARGE ROBOTS.

THIS TYPE OF SYSTEM GIVES THE ROBOT A MECHANICAL SIMPLICITY, MAINTAINS A HIGH STRENGTH AND SPEED, AND GETS MORE ACCURATE CONTROL.

CLASSIFIED BY TECHNOLOGY LEVELS (CONTINUED)

THERE ARE SEVERAL CHARACTERISTICS WHICH DISTINGUISH THE LOW TECHNOLOGY INDUSTRIAL ROBOT FROM MEDIUM OR HIGH TECHNOLOGY INDUSTRIAL ROBOTS. SEE FIGURE 1-4-2.

FIG. 1-4-2

	TECHNOLOGY LEVELS		
CHARACTERISTICS	LOW	MEDIUM	HIGH
DEGREE OF FREEDOM	1TO 4 AXES	UP TO SIX	UP TO TEN
MOTION OF END EFFECTOR	POINT TO POINT	CONTINUOUS PARTS	CONTINUOUS PATH
CONTROLLER	SIMILAR TO HARD AUTOMATION DEVICES. CANNOT LEARN.	HAVE LEARNING ABILITY. PROGRAMMABLE.	HAVE LEARNING ABILITY. PROGRAMMABLE.
TYPE OF DRIVING SYSTEM	PNEUMATIC HYDRAULIC AIR/OIL	PNEUMATIC HYDRAULIC ELECTRICAL	PNEUMATIC HYDRAULIC ELECTRICAL
ACCURACY	HIGH	FAIR	LOW

LESSON PLAN #4

UNIT 1 - INTRODUCTION TO ROBOTS

ASSIGNMENT SHEET 1

AFTER READING THE INFORMATION SHEETS (IS1-4-1 THROUGH IS1-4-5) PROVIDED, COMPLETE THE FOLLOWING QUESTIONS IN WRITING OR AS REQUESTED BY YOUR INSTRUCTOR.

1. WHAT IS MEANT BY THE SENSORY CONTROLLED ROBOT?

2. LIST FOUR APPLICATIONS OF CONTINUOUS PATH ROBOTS.

3. WHAT ARE THE COMMON CHARACTERISTICS OF NON-SERVO CONTROLLED ROBOTS?

4. THE ACCURACY AND REPEATABILITY IN CONTINUOUS PATH ROBOTS DEPEND ON WHAT KINDS OF FACTORS?

5. WHAT ARE THE ADVANTAGES OF HYDRAULIC DRIVEN SYSTEMS USED IN A ROBOT?

6. THERE ARE SEVERAL CHARACTERISTICS TO CLASSIFY THE ROBOT TECHNOLOGICAL LEVELS. WHAT ARE THEY?

SYLLABUS SHEET FOR LESSON 5
ROBOT SERVICE AND REPAIR

UNIT #1 INTRODUCTION TO ROBOT

CONFIGURATION AND END EFFECTORS

LESSON OBJECTIVE--UPON COMPLETION OF THIS LESSON, THE STUDENT SHOULD BE ABLE TO:

1. VERBALLY DESCRIBE THE GEOMETRIC CONFIGURATION OF ROBOTS.
2. VERBALLY DESCRIBE THE TYPES OF END EFFECTORS.
3. VERBALLY DESCRIBE THE APPLICATION OF VACUUM CUPS, AND MAGNETIC PICK-UPS.

TEACHING AIDS:

1.	H1-5-1	LESSON SYLLABUS SHEET
2.	T1-5-1	CUBIC (CARTESIAN) COORDINATE SYSTEM
3.	T1-5-2	CYLINDRICAL COORDINATE SYSTEM
4.	T1-5-3	JOINTED COORDINATE SYSTEM
5.	T1-5-4	POLAR COORDINATE SYSTEM
6.	T1-5-5	7 DEGREES OF FREEDOM

INFORMATIONAL ASSIGNMENTS:

1.	IS1-5-1	GEOMETRIC CONFIGURATION OF ROBOT
2.	IS1-5-2	END EFFECTORS
		ANSWER QUESTIONS FOUND ON ASSIGNMENT SHEETS
1.	AS1-5-1	CONFIGURATION AND END EFFECTORS

STEP 1-INTRODUCTION FOR PREPARATION OF THE STUDENT:

THE MAJOR CONSIDERATION OF A ROBOT IS: IT MUST BE ABLE TO REACH WORKPIECES OR PARTS IN ITS WORKING ENVIRONMENT. USUALLY THIS REQUIREMENT WILL BE DONE BY THE COMBINATION OF AN ARM AND WRIST SUB-ASSEMBLY. THE ROBOT'S SPHERE OF INFLUENCE IS BASED UPON THE VOLUME INTO WHICH THE ROBOT'S ARM CAN DELIVER THE WRIST SUB-ASSEMBLY. BESIDES THESE, THE HAND OR CALLED END EFFECTORS ARE ALSO IMPORTANT FOR THE ROBOT TO BE USED IN DIFFERENT ENVIRONMENTS.

IN THIS UNIT, THE STUDENT WILL LEARN THE DIFFERENT KINDS OF ARM CONFIGURATIONS AND THEIR RELATED MOVING COMPONENTS WHICH HAVE TO GRASP, LIFT AND MANIPULATE WORKPIECES AND WORKING TOOLS. IN ADDITION, THE STUDENT WILL ALSO BE TAUGHT ABOUT SOME SPECIAL END EFFECTORS USED IN INDUSTRY TODAY.

LESSON SUMMARY AND REVIEW:

1. HOW MANY KINDS OF MANIPULATER CONFIGURATIONS HAVE BEEN USED?

2. WHAT ARE THE END EFFECTORS?

3. WHAT ARE THE ADVANTAGES OF USING VACUUM CUPS?

4. WHAT ARE THE SURFACE CONDITIONS OF USING MAGNETIC PICK-UPS?

GEOMETRIC CONFIGURATION OF ROBOTS

1. BASIC CONFIGURATION

A ROBOT MUST BE ABLE TO REACH WORKPIECES AND TOOLS. THIS REQUIRES A COMBINATION OF AN ARM AND A WRIST SUB-ASSEMBLY, PLUS A HAND, COMMONLY CALLED AN END EFFECTOR OR A GRIPPER. THE ROBOT'S SPHERE OF INFLUENCE IS BASED UPON THE VOLUME INTO WHICH THE ROBOTS CAN DELIVER THE WRIST SUB-ASSEMBLY.

A VARIETY OF GEOMETRIC CONFIGURATIONS HAVE BEEN STUDIED AND TRIED AND THEIR RELATIVE KINEMATIC CAPABILITIES WERE APPRAISED. SO FAR, THE MANUFACTURERS HAVE SELECTED ONE OR MORE OF THE FOLLOWING:

A. CUBIC (CARTESIAN) COORDINATE
B. CYLINDRICAL COORDINATE
C. JOINT COORDINATE
D. POLAR COORDINATE

EVIDENTLY, EACH OF THESE CONFIGURATIONS OFFERS A DIFFERENT SHAPE TO ITS SPHERE OF INFLUENCE, THE TOTAL VOLUME OF WHICH DEPENDS UPON ARM LINK LENGTHS. FOR DIFFERENT APPLICATIONS DIFFERENT CONFIGURATIONS MAY BE APPROPRIATE.

2. CUBIC (CARTESIAN) COORDINATE

T THE ROBOT CONSTRUCTION CONSISTS OF THREE OTHOGONAL SLIDES WHICH ARE PARALLEL TO THE X, Y. AND Z. AXIS OF THE CARTESIAN COORDINATE SYSTEM. THESE SLIDES ENABLE THE ROBOT TO MOVE ITS ARM TO ANY POINT WITHIN ITS 3-DIMENSION RECTANGULARLY SHAPED WORK SPACE. (SEE FIG. 1-5-1)

3. CYLINDRICAL COORDINATE

THE ROBOT BODY IS A VERTICAL COLUMN THAT SWIVELS ABOUT A VERTICAL AXIS. THE ARM CONSISTS OF SEVERAL OTHOGONAL SLIDES WHICH ALLOWS THE ARM TO BE MOVED UP OR DOWN, AND IN OR OUT WITH RESPECT TO THE BODY. A CYLINDRICAL COORDINATE ARM MIGHT BE BEST SUITED TO A STRAIGHT THRUST BETWEEN THE DIES OF A PUNCH PRESS. (SEE FIG. 1-5-2)

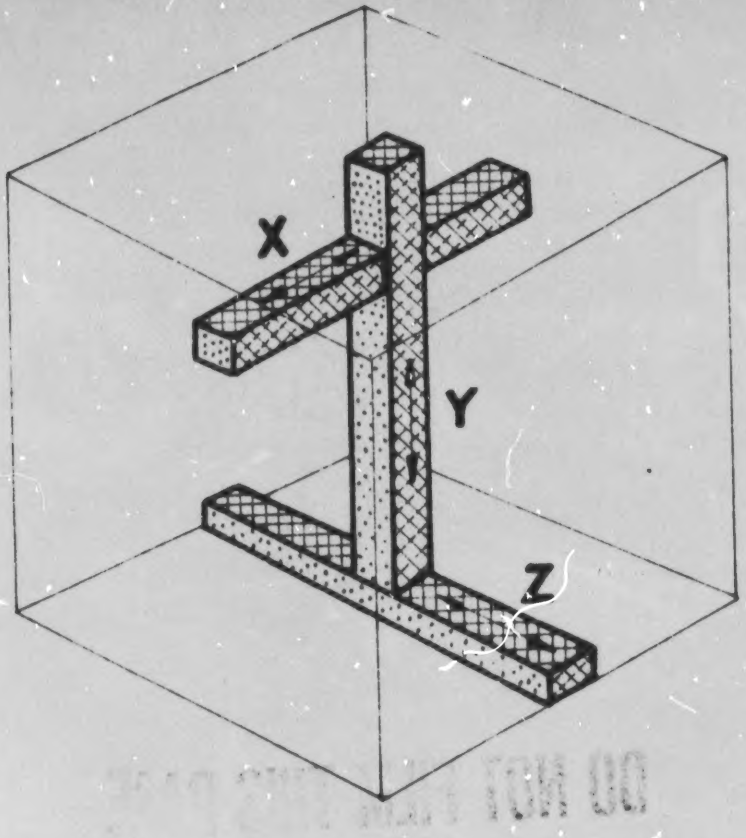


FIG. 1-5-1 CUBIC (CARTESIAN) COORDINATE SYSTEM
X. Y. Z.: 3 LINEAR AXES

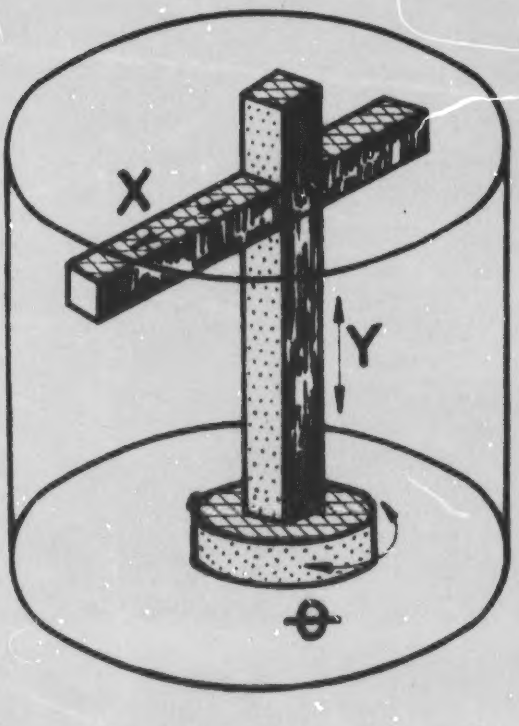


FIG. 1-5-2 CYLINDRICAL COORDINATE SYSTEM
X. Y.: 2 LINEAR AXES θ: 1 ROTATIONAL AXIS

4. JOINT COORDINATE

THE ROBOT ARM CONSISTS OF SEVERAL STRAIGHT MEMBERS CONNECTED TO THE HUMAN SHOULDER, ELBOW AND WRIST. THIS ARM IS MOUNTED TO A BASE WHICH CAN ROTATE TO ALLOW THE ROBOT TO WORK WITHIN A GUASI-SPHERE SPACE. THESE KINDS OF ARMS MIGHT BE BEST FOR REACHING INTO A TUB WORK. (SEE FIG. 1-5-3.)

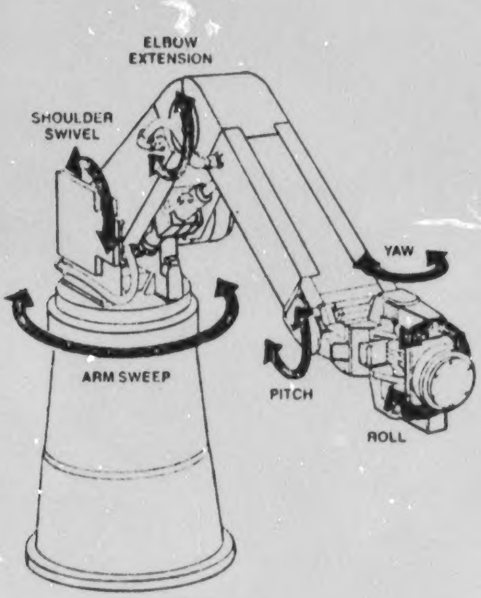

ELBOW EXTENSION
SHOULDER SWIVEL
YAW
ARM SWEEP
PITCH
ROLL

FIG. 1-5-3 JOINTED COORDINATE SYSTEM
1 LINEAR AXIS
2 ROTATIONAL AXES

5. POLAR COORDINATE

THE WORK SPACE IN WHICH THE ROBOT CAN MOVE ITS ARM IS A PARTIAL SPHERE. THE ROBOT IS EQUIPPED WITH A ROTARY BASE AND A PIVOT WHICH CAN BE USED TO RAISE AND LOWER A TELESCOPING ARM. (SEE FIG. 1-5-4.)

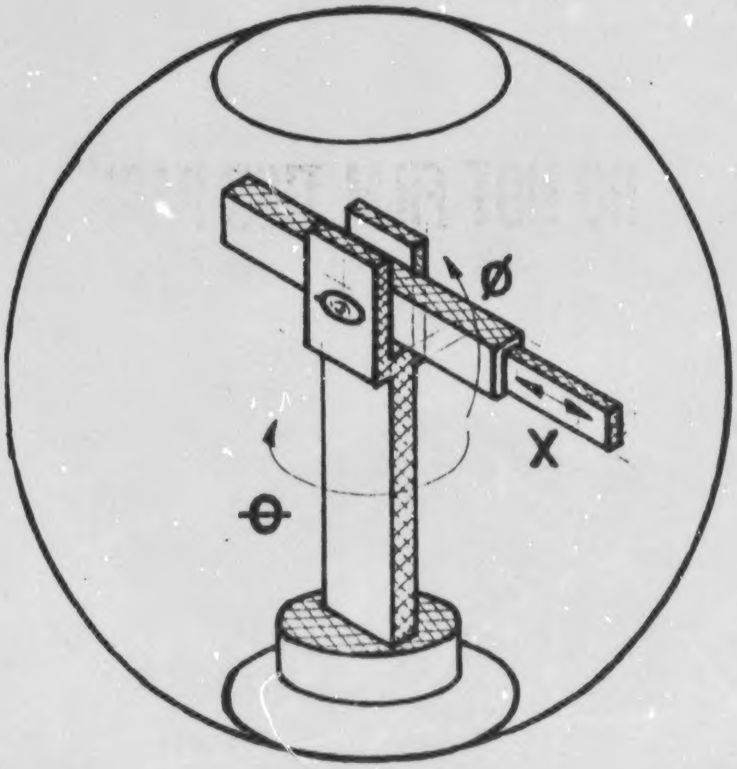


FIG. 1-5-4 POLAR COORDINATE SYSTEM M
X = 1 LINEAR AXIS
$\theta . \phi$ = 2 ROTATIONAL AXES

6. WRIST ASSEMBLY

IN EVERY CASE THE ARM CARRIES A WRIST ASSEMBLY TO ORIENT ITS END EFFECTOR AS DEMANDED BY WORKPIECE HANDLING. WRIST ACTION IS USUALLY USED TO PROVIDE A ROBOT WITH AN EVEN GREATER AMOUNT OF FLEXIBILITY.

IN ADDITION TO THE THREE DEGREES OF FREEDOM PROVIDED BY THE ROBOT'S MANIPULATOR, COMMONLY THE WRIST PROVIDES THREE ARTICULATIONS THAT OFFER EXTRA MOTIONS LABELED PITCH, YAW, AND ROLL. THESE THREE ARTICULATIONS CAN BE USED EFFECTIVELY FOR TASKS SUCH AS LOADING AND UNLOADING, AS SHOWN IN FIGURE 1-5-5.

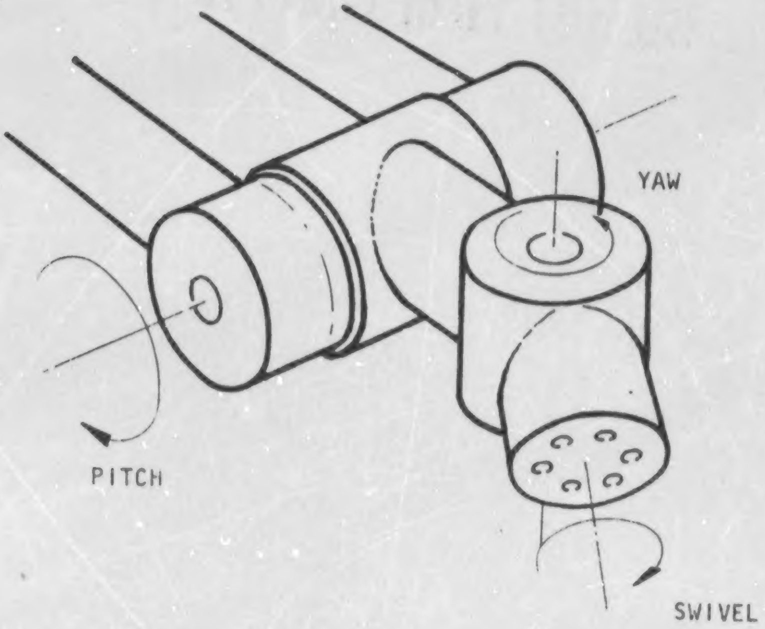


FIG. 1-5-5 WRIST ARTICULATION

END EFFECTORS

1. WHAT ARE THE END EFFECTORS?

THE END EFFECTOR IS THE DEVICE THAT PERFORMS THE ACTUAL WORK. IT IS A TOOL OR GRIPPER WHICH IS ATTACHED TO THE MOUNTING SURFACE OF THE MANIPULATOR WRIST WHICH HAS TO GRASP, LIFT, AND MANIPULATE WORKPIECES WITHOUT CAUSING ANY DAMAGE, AND WITHOUT LETTING GO. COMPARED WITH HUMAN HANDS, THESE END EFFECTORS OF THE ROBOT ARE VERY LIMITED. THEY HAVE FEWER ARTICULATIONS AND THEY ARE ALSO WITHOUT ANY SENSE OF FEELING OR TOUCH. BUT, THEY CAN BE DESIGNED TO WITHSTAND HIGH TEMPERATURES SO THAT THEY ARE ABLE TO WORK WITH PARTS THAT ARE RED HOT, AND THEY ARE ALSO BETTER AT DEALING WITH OBJECTS WHICH HAVE SHARP EDGES, OR COVERED WITH CORROSIVE SUBSTANCES, OR WHICH ARE SIMPLY TOO HEAVY FOR HUMAN HANDS TO LIFT.

SINCE END EFFECTORS OF THE ROBOT ARE LESS ADAPTABLE THAN HUMAN HANDS, SO THEY HAVE TO BE DESIGNED OR CHOSEN ESPECIALLY FOR A PARTICULAR INDUSTRIAL APPLICATION. USUALLY, THE EFFECTORS ARE NOT SO FLEXIBLE, THEY MAY HAVE TO BE INCLUDED ALONG WITH THE SPECIAL TOOLING REQUIREMENTS OF THE JOB.

END EFFECTORS ARE OFTEN CALLED GRIPPERS, ALTHOUGH THIS IMPLIES ONLY ONE FORM OF EFFECTORS. IN PRACTICE, ONE TYPE OF AN END EFFECTOR IS USUALLY GOING TO BE SUITABLE FOR A WIDE RANGE OF DIFFERENT JOBS AT A PARTICULAR WORK STATION. ONLY WHEN THE ROBOT HAS TO BE MOVED TO SOMEWHERE TO WORK ON AN ENTIRELY DIFFERENT PROCESS IS IT LIKELY THAT THE HAND TOOLING HAS TO BE CHANGED. HOWEVER, COMPARED WITH OVERALL PLANT AND MACHINERY COSTS, ROBOT EFFECTORS CAME RELATIVELY CHEAP.

THERE ARE SEVERAL KINDS OF ROBOT HANDS USED IN INDUSTRY TODAY. THESE ARE DEPENDING TO A LARGE EXTENT ON THE NATURE OF THE MATERIAL BEING PROCESSED.

THEY ARE:

A. STANDARD HANDS
   - -MECHANICAL GRIPPERS
   - -VACUUM CUPS
   - -ELECTROMAGNETS
   - -WELD GUNS
   - -TORCHES
   - -SPRAYERS

B. NON-STANDARD HANDS
- -MULTI-FUNCTION HANDS
- -INTERCHANGEABLE HANDS

A SAMPLE "SCISSORS"-ACTION GRIPPERS IS SHOWN IN FIGURE 1-5-6.

II IF AN APPLICATION NEEDS A GRIPPER TO REMOVE A FINISHED PART AND REPLACE IT WITH AN UNFINISHED PART, A TWO-GRIPPER HAND CAN BE USED AS SHOWN IN FIGURE 1-5-7.

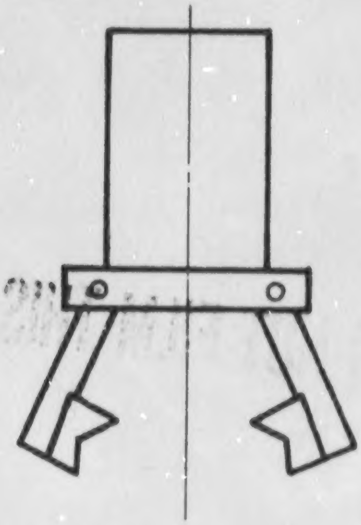


FIG. 1-5-6 SCISSORS-ACTION GRIPPER

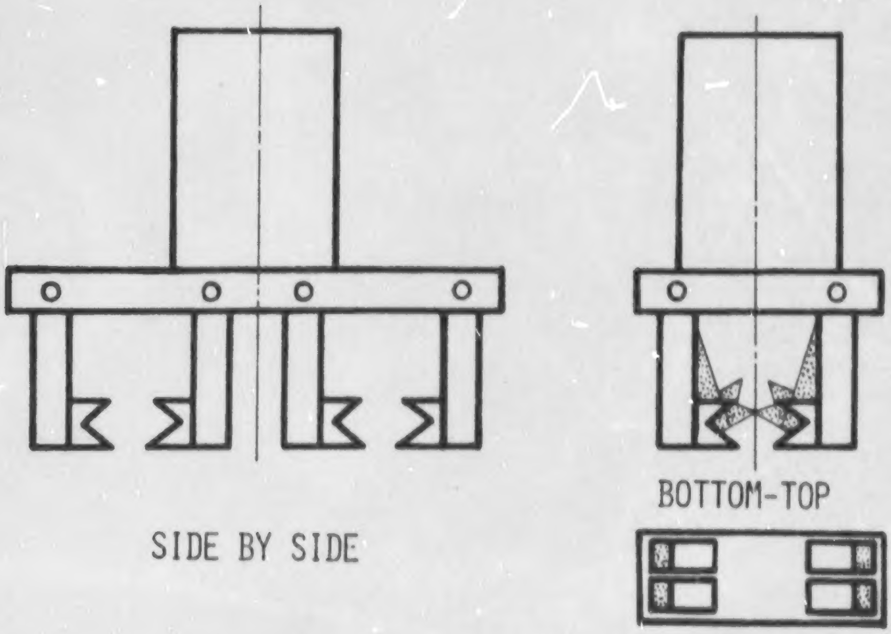
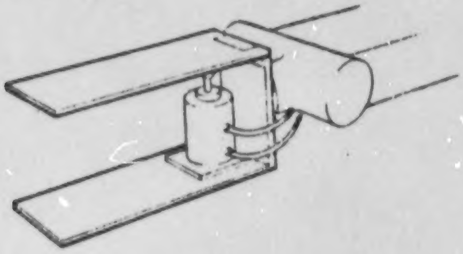
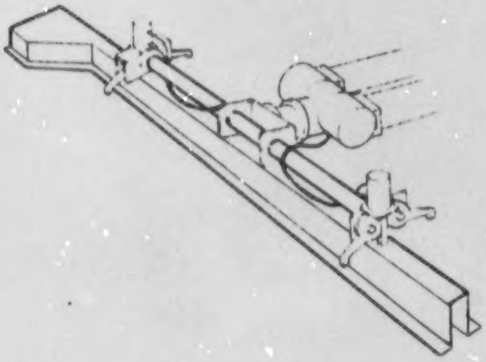


FIG. 1-5-7 REMOVES FINISHED PARTS, INSERTS UNFINISHED PARTS.

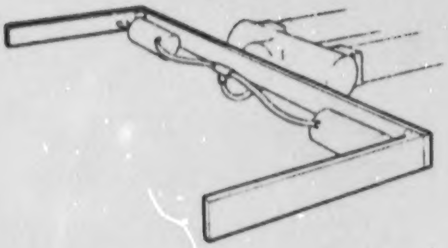
THERE ARE SOME SPECIAL END EFFECTORS CURRENTLY BEING USED IN INDUSTRY, AS SHOWN IN FIGURES 1-5-8.



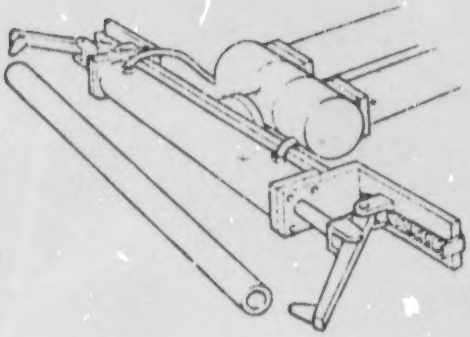
1. HAND WITH ONE MOVABLE JAW



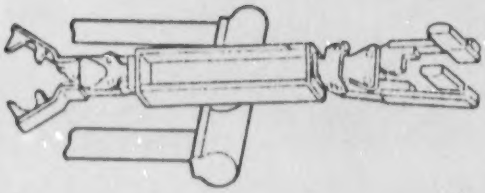
2. HAND WITH MODULAR GRIPPER



3. HAND FOR CARTONS



4. HAND FOR GLASS TUBES



5. DOUBLE HAND FOR INSIDE AND OUTSIDE WORK.

FIG. 1-5-8 SPECIAL HANDS OF INDUSTRIAL ROBOTS

2. GRIPPING FORCE.

IN GENERAL CONCEPT HOW HARD THE ROBOT MUST GRASP THE PART DEPENDS ON FOLLOWING THREE FACTORS.

A. THE WEIGHT OF THE PART

B. THE FUNCTION BETWEEN THE PART AND THE FINGERS (VACUUM CAPS OR MAGNET PICK-UPS)

C. HOW FAST THE ROBOT IS TO MOVE AND THE RELATION BETWEEN THE DIRECTION OF MOVEMENT TO THE FINGER'S POSITION ON THE PART

A ROBOT AT NORMAL FULL SPEED MAY, DURING ACCELERATION AND DECELERATION, V VERY WELL EXERT FORCES ON A PART OF ABOUT 2G. (TWICE THE EARTH'S GRAVITY). THE WORST CASE IS WHEN THE ACCELERATION OR DECELERATION FORCES ARE PARALLEL TO THE CONTACT SURFACE OF THE FINGERS. THE FOLLOWING RELATIONSHIPS ARE OF INTEREST:

A. A PART TRANSFERRED BY A ROBOT IN HORIZONTAL PLANE WILL EXERT A FORCE ON THE HAND TOOLING OF TWICE THE WEIGHT OF THE PART.

B. IF THE PART IS LIFTED IT WILL EXERT A FORCE THREE TIMES ITS WEIGHT--1G. DUE TO THE EARTH GRAVITY AND 2G. DUE TO THE ACCELERATION UPWARDS MADE BY THE ROBOT.

EXAMPLE 1

A WEIGHT OF 30 LBS. IS TO BE LIFTED BY A ROBOT. THE GRAVITATIONAL FORCES ARE PARALLEL TO THE CONTACT SURFACES OF THE FINGERS AND TEND TO PULL THE WEIGHT OUT OF THE HAND. IF THE FRICTION COEFFICIENT IS 0.16, HOW HARD MUST THE ROBOT GRASP THE PART? THE REASONABLE SAFETY FACTOR IS 2.

SOLUTION

EQUATION:

(CLAMPING FORCE) x (FRICTION COEFFICIENT) = TANGENTIAL FORCE
= WEIGHT OF THE PART x LOADING(G)

CLAMPING FORCE x 0.16 = 30 x (3G)
= 90

CLAMPING FORCE = 562.5

TAKE 2 FOR SAFETY FACTOR:
THEN:

CLAMPING FORCE = 562.5 x 2
1125.00 LB.

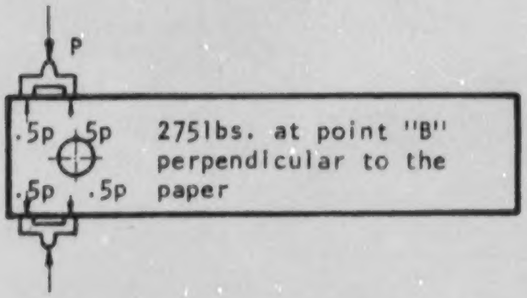
IF THE CENTER OF GRAVITY OF THE PART IS OUTSIDE THE LINE BETWEEN THE TWO JAWS, A MOMENT DUE TO ACCELERATION FORCES WILL TEND TO PIVOT THE PART. TO PREVENT PIVOTING THE PRODUCT OF THE CLAMPING FOR THE SPREAD BETWEEN CONTACT POINTS AND FRICTION MUST BE GREATER THAN THE MOMENT.

EXAMPLE 2

A PART WEIGHING 25 LBS. HAS A CENTER OF GRAVITY 10 INCHES OFF THE POINT WHERE IT IS GRASPED. THE FRICTION COEFFICIENT IS 0.15 AND THE SPREAD BETWEEN THE CONTACT POINT ON EACH JAW PAD IS 3 INCHES. HOW HARD MUST THE ROBOT GRASP TO HAVE A SAFETY FACTOR OF 2 ON ITS HOLD OF THE PART?

SOLUTION

REFER THE FIGURE BELOW.



A. (CLAMPING FORCE) x (FRICTION COEFFICIENT) - FORCE AT POINT B.

$2 \times (0.5P \times U) = B$

$2 \times (0.5 \times P \times 0.15) = 275$

$P = \frac{275}{0.15}$

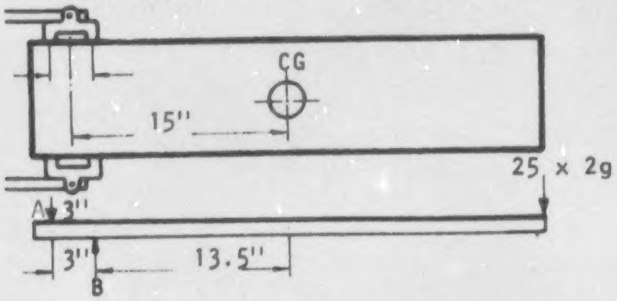
$= 1830$ LBS.

B. WITH A SAFETY FACTOR OF 2, THEN:

$P = 1830 \times 2 = 3660$ (LBS.)

THIS IS A VERY LARGE CLAMPING FORCE FOR A 30 LB. PART, WHICH INDICATES THAT THE DESIGN IS NOT EFFICIENT. THE FORCE CAN BE REDUCED IN TWO WAYS:

A. TRY TO GRASP THE PART CLOSER TO CG OR
B. MAKE THE PADE LONGER, SAY 6" INSTEAD OF 3"
C. THE SITUATION MAY BE REPRESENTED THUS:



FORCE AT A $= \frac{25x^2}{3} \times 13.5 = 225$LB.

$B = 225 + (25 \times 2) = 275$LB.

3. VACUUM SYSTEM

THERE ARE SOME DIFFERENT KINDS OF PARTS SUCH AS NON-FERROUS MATERIALS, FRAGILE PARTS, PLASTICS, ETC., WHICH ARE HANDLED EASILY BY VACUUM HANDS. USUALLY THE VACUUM PICK-UP HAS THE VIRTUES OF THE MAGNETIC PICK-UP AND IS MUCH LESS SUSCEPTIBLE TO A WORKPIECE SIDE SLIP.

IN VACUUM SYSTEM, THE VACUUM CUPS ARE NORMALLY USED. VACUUM CUPS ARE USUALLY MADE OF AN ELASTIC MATERIAL THAT CONFORMS AND FORMS A SEAL TO THE SURFACE OF THE PART TO BE HANDLED. FOR THE

ROUGH OR POROUS SURFACE, SUCH AS BRICKS, THE VACUUM CUPS ARE MADE OF CELLULAR MATERIAL THROUGH WHICH THE AIR IS DRAWN.

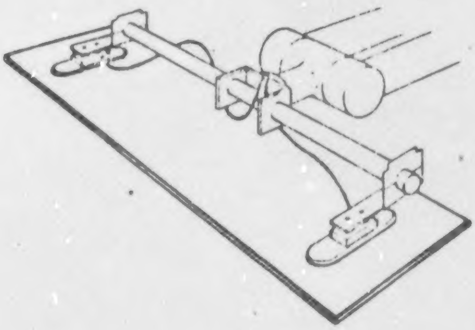
THE HOLDING FORCE OF THE VACUUM CUP IS THE EFFECTIVE AREA MULTIPLIED BY THE DIFFERENT PRESSURES BETWEEN THE OUTSIDE AND INSIDE OF THE CUP. THE EFFECTIVE AREA OF A CUP IS OFTEN NOT THE GEOMETRIC AREA, BECAUSE THE CUP IS OFTEN DEFORMED WHEN THE VACUUM IS APPLIED. IF THE BOTTOM OF THE CUP TOUCHES THE OBJECT TO BE LIFTED, THE EFFECTIVE AREA IS REDUCED CORRESPONDINGLY.

TO GET THE BEST UTILIZATION OF A CUP, THE LARGEST POSSIBLE VACUUM OR PRESSURE DIFFERENTIAL SHOULD BE USED. IT IS BETTER TO USE A LARGER CUP AND A LOWER VACUUM TO OBTAIN A FASTER SYSTEM.

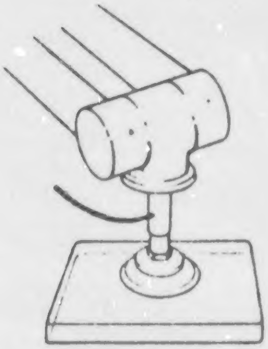
THE LIFE OF VACUUM CUPS IS QUITE GOOD, PARTICULARLY IN RELATION TO THEIR PRICE. POLYURETHANE CUPS SEEM TO HAVE A LONGER LIFE THAN THOSE MADE FROM NATURAL SYNTHETIC RUBBER. VACUUM CUPS ARE CATALOG ITEMS AND THERE IS A SELECTION TO CHOOSE FROM IN BOTH CONFIGURATIONS AND SIZES.

THE NUMBER OF CUPS TO BE USED IN A DESIGN DEPENDS ON THE FACTORS OF WEIGHT OF THE LOAD, SIZE OF CUPS AVAILABLE, LOCATION OF THE CENTER OF GRAVITY, AND THE SUPPORT NEEDED TO HANDLE LARGE FLIMSY PARTS (ENGELBERGER, 1980).

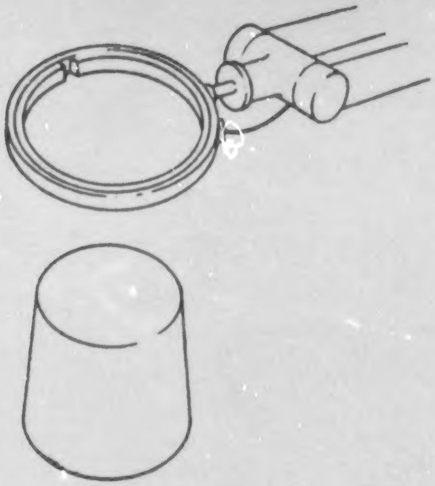
SOME TYPICAL VACUUM PICK-UP SYSTEMS ARE SHOWN IN FIG. 1-5-9.



1. VACUUM CUP HAND WITH 2 CUPS



2. SIMPLE VACUUM CUP HAND



3. EXPANSION BLADDER HAND

FIG. 1-5-9 VACUUM PICK-UPS

4. MAGNETIC PICK-UPS

AS MENTIONED BEFORE THERE ARE SEVERAL WAYS TO USE MATERIALS OR PARTS IN HANDLING. IF THE PARTS ARE OF FERROUS CONTENT, THE MAGNETIC METHODS WILL BE CONSIDERED TO BEING USED.

MAGNETS CAN BE SCIENTIFICALLY DESIGNED AND MADE IN DIFFERENT KINDS OF SHAPES AND SIZES TO PERFORM VARIOUS TASKS. A FERROUS OBJECT PLACED WITHIN THE RANGE OF A MAGNET WILL BECOME MAGNETIZED, AND WILL THEN HAVE ITS OWN NORTH AND SOUTH POLES WHICH WILL BE ATTRACTED TO THE PARENT OF LARGER MAGNET IN PROPORTION TO ITS MASS.

MAGNETS FALL INTO TWO MAJOR CATEGORIES, NAMELY PERMANENT AND ELECTRO. ELECTRO MAGNETS ARE WELL SUITED FOR REMOTE CONTROL AS WELL AS FOR THE MODERATELY HIGH SPEED PICK-UP AND RELEASE OF PARTS. BASICALLY, IT IS A MULTI-FUNCTION SWITCH THROUGH WHICH POWER IS SUPPLIED TO THE MAGNET AND AS IT INTERRUPTS THE POWER SUPPLY, IT REVERSES THE POLARITY AND SUPPLIES POWER AT A REDUCED VOLTAGE FOR A SHORT DURATION BEFORE COMPLETELY DISCONNECTING THE MAGNET FROM THE LINE. THE REVERSE POLARITY TENDS TO CANCEL ANY RESIDUAL MAGNETISM IN THE PART TO MAKE SURE THAT IT WILL RELEASE INSTANTANEOUSLY. PERMANENT MAGNETS DO NOT REQUIRE A POWER SOURCE FOR OPERATION WHICH MAKES THEM WELL ADAPTED FOR HAZARDOUS ATMOSPHERES THAT REQUIRE EXPLOSION PROOF ELECTRICAL EQUIPMENT. HOWEVER, THEY DO NEED A MEANS OF SEPARATING MATERIAL FROM THE MAGNET. TO ACCOMPLISH THIS, A STRIPPER DEVICE MAY BE EMPLOYED.

THERE ARE SEVERAL IMPORTANT POINTS THAT MUST BE CONSIDERED BEFORE A PROPER SELECTION OF WHETHER A PERMANENT OR ELECTRO MAGNET IS EMPLOYED.

A. SHAPE OF PART
PARTS HAVING A LARGE FLAT CONTACT SURFACE ARE GOOD FOR MAGNETIC HANDLING. OTHER KINDS OF SHAPES CAN BE HANDLED, BUT MORE COMPENSATION MUST THEN BE MADE.

B. WEIGHT
THE LIFTING CAPABILITY OF THE MAGNET MUST BE GREAT ENOUGH THAN THE HEAVIEST PART TO BE MANIPULATED.

C. TEMPERATURE
ELECTROMAGNETS ARE USUALLY DESIGNED FOR HANDLING THE PARTS OF TEMPERATURE WITHIN 300 F. SOME SPECIAL DESIGNS CAN BE MADE FOR HIGHER TEMPERATURES. PERMANENT MAGNETS HANDLE MOST EASILY WITHIN 200 F. SOMETIMES, THEY HAVE BEEN DESIGNED FOR HANDLING PARTS UP TO 900 F.

D. SURFACE CONDITION
A SMOOTH, FLAT, DRY, CLEAN SURFACE IS IDEALLY SUITED FOR MAGNETIC PARTS HANDLING; OTHERWISE IT WILL AFFECT THE HOLDING POWER SO RUST, MILL SCALE, OIL PITS AND SAND MANNERS WILL MINIMIZE AS FAST AS POSSIBLE.

E. POSITION TO BE HANDLED
THE MOST EFFICIENT WAY OF HANDLING PARTS WITH MAGNETIC EFFECTORS IS THE PARTS DIRECTLY BENEATH THE MAGNET HAND. THERE IS ONLY 25% OR LESS OF ITS MAXIMUM POTENTIAL MAGNETIC FORCE WHEN THE MAGNET FACE IS IN A VERTICAL PLANE WITH PARTS.

A TYPICAL ELECTROMAGNETIC PICK-UP DESIGNED FOR USE WITH FLAT SURFACES IS AS SHOWN IN FIGURE 1-5-10.

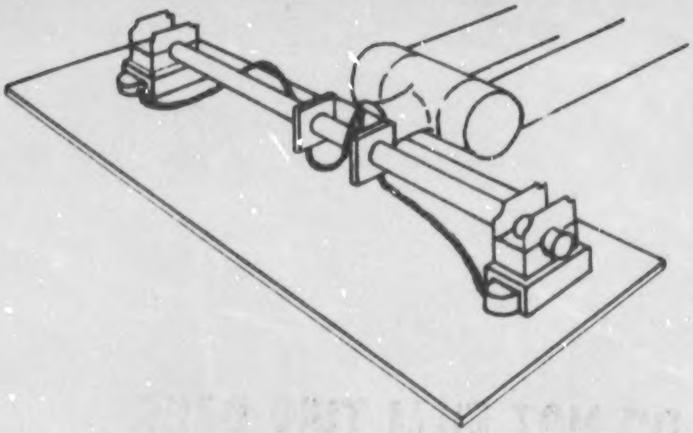
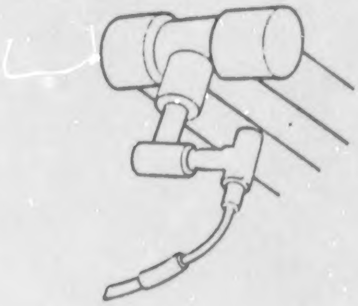


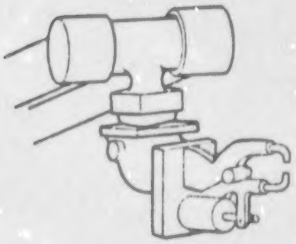
FIG. 1-5-10 TYPICAL ELECTROMAGNETIC PICK-UP DESIGN FOR USE WITH FLAT SURFACE.

5. TOOLS

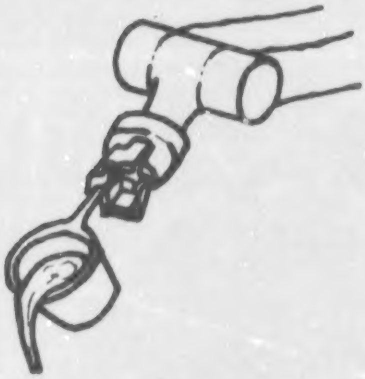
BESIDES VARIOUS GRASPING AND PICK-UP DEVICES, THERE ARE MANY DIFFERENT KINDS OF TOOLS TO BE USED ON ROBOTS, SUCH AS SPRAY PAINTING GUN, WELDING TORCH AND OTHER DEVICES, SHOWN IN FIG. 1-5-11.



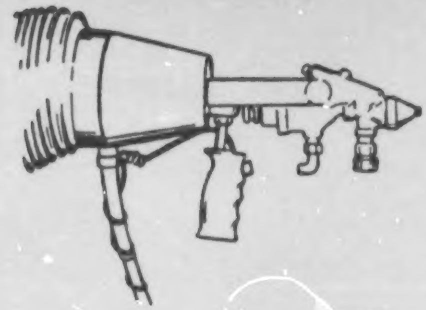
1. TOOL-MIG WELDING TORCH



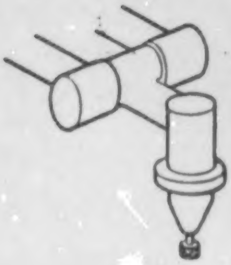
2. TOOL-SPOT WELDING GUN



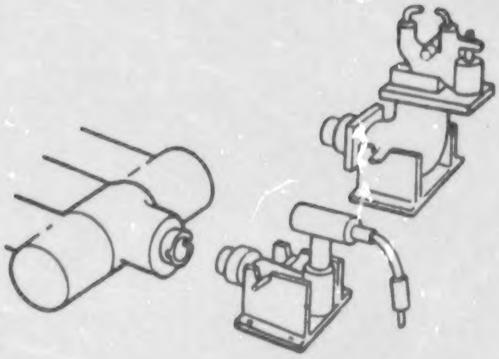
3. TOOL-LADLE USED FOR HOT MELT ON METAL IN A FOUNDRY SHOP OR DIECASTING PROCESSES



4. TOOL-SPRAYPAINTING GUN



5. TOOL-ROUTER OR DEBURRING DEVICE



6. TOOL-UNIVERSAL TOOL CHANGING
DEVICE

FIG. 1-5-11 ROBOT'S TOOLS

LESSON PLAN #5

UNIT 1--CONFIGURATION AND END EFFECTORS

ASSIGNMENT SHEET 1

AFTER READING THE INFORMATION SHEET (IS1-5-1 AND IS1-5-2) PROVIDED, COMPLETE THE FOLLOWING QUESTIONS IN WRITING OR AS REQUESTED BY YOUR INSTRUCTOR.

1. WHAT ARE THE USES OF A TWO-GRIPPER HAND?

2. WHAT ARE THE FACTORS TO DETERMINE THE FORCE OF A GRIPPER TO GRASP A PART?

3. IN DESIGNING A VACUUM CUP, WHAT ARE THE CRITICAL FACTORS THAT SHOULD BE CONSIDERED?

4. THERE ARE SEVERAL IMPORTANT POINTS THAT MUST BE CONSIDERED BEFORE A PROPER SELECTION IN USING PERMANENT OR ELECTRO MAGNET END EFFECTORS WHAT ARE THEY?

SYLLABUS SHEET FOR LESSON 6
ROBOT SERVICE AND REPAIR

UNIT #2 POWER SUPPLY

HYDRAULIC POWER SYSTEM

LESSON OBJECTIVE--UPON COMPLETION OF THIS LESSON, THE STUDENT SHOULD BE ABLE TO:

1. EXPLAIN THE FUNCTION OF THE BASIC COMPONENTS OF A HYDRAULIC SYSTEM.
2. USE A RELATED FORMULA TO CALCULATE THE HYDRAULIC SYSTEM DATA.
3. DESCRIBE THE OPERATION OF THE HYDRAULIC SYSTEM.

TEACHING AIDS:

1.	H2-1-1	LESSON SYLLABUS SHEET
2.	T2-1-1	BASIC HYDRAULIC SYSTEM
3.	T2-1-2	PUMP CLASSIFICATION
4.	T2-1-3	PUMPS
5.	T2-1-4	PISTON PUMPS
6.	T2-1-5	VALVES
7.	T2-1-6	PRESSURE REDUCING VALVES
8.	T2-1-7	CYLINDER
9.	T2-1-8	OPERATION OF PRESSURE REDUCING VALVE
10.	T2-1-9	FORMULA OF PUMPS
11.	T2-1-10	FORMULA OF CYLINDERS

INFORMATIONAL ASSIGNMENTS:

1.	IS2-1-1	INTRODUCTION
2.	IS2-1-2	RESERVOIRS
3.	IS2-1-3	HYDRAULIC PUMPS
4.	IS2-1-4	VALVES
5.	IS2-1-5	ACTUATOR-CYLINDERS
6.	IS2-1-6	ACTUATOR-MOTORS
		ANSWER QUESTIONS FOUND ON ASSIGNMENT SHEETS
1.	AS2-1-1	HYDRAULIC POWER SYSTEM

REFERENCES:

OSTER, JON, BASIC APPLIED FLUID POWER; HYDRAULICS, MCGRAW-HILL BOOK COMPANY, NEW YORK, 1969.

PEASE, D.A., BASIC FLUID POWER, PRENTICE-HALL, INC. 1969.

SULLIVAN, J.A. FLUID POWER-THEORY AND APPLICATION, RESTON PUBLISHING COMPANY, 1982.

STEP 1-INTRODUCTION FOR PREPARATION OF THE STUDENT:

THE USE OF HYDRAULIC POWER HAS GROWN SO RAPIDILY IN THE INDUSTRIAL FIELD, ESPECIALLY IN THE INDUSTRIAL ROBOTIC AREA, WHERE HYDRAULIC POWER HAS BEEN WIDELY USED. TODAY, MOST OF THE ROBOTS HAVE DEALT CLOSELY WITH IT.

IN THIS UNIT, THE STUDENT WILL UNDERSTAND THE FUNCTIONS OF THE COMPONENTS USED IN A HYDRAULIC SYSTEM, AND A SYSTEM'S PERFORMANCES AND ITS OPERATIONS IN THE ROBOTIC APPLICATION ENVIRONMENT.

LESSON SUMMARY AND REVIEW:

1. IN A HYDRAULIC SYSTEM, IT BASICALLY CONTAINS FOUR COMPANENTS. WHAT ARE THEY

2. WHAT IS THE FUNCTION OF A RESERVOIR?

3. NAME THE FOUR POPULAR FIXED DISPLACEMENT HYDRAULIC PUMPS.

4. WHAT ARE THE THREE IMPORTANT THINGS THAT ARE CONTROLLED IN A HYDRAULIC SYSTEM

5. WHAT IS THE SIMPLEST TYPE OF A DIRECTIONAL CONTROL VALVE?

6. WHAT IS THE FUNCTION OF A HYDRAULIC CYLINDER IN A HYDRAULIC SYSTEM?

7. NAME THREE KINDS OF HYDRAULIC MOTORS.

INTRODUCTION

1. TERMS AND DEFINITIONS.
    - A. HYDRAULICS - THE STUDY OF FLUIDS IN MOTION OR REST.
    - B. FLUID - A SUBSTANCE WHICH HAS NO SHAPE OF ITS OWN.
    - C. PRESSURE - THE FORCE EXERTED OVER A SURFACE DIVIDED BY ITS AREA. P=F/A.
    - D. LIQUID - A FLUID WHICH IS RELATIVELY INCOMPRESSIBLE. (BUT, A GAS IS A FLUID THAT CAN BE COMPRESSED)
    - E. RESERVOIR - A CONTAINER FOR KEEPING A SUPPLY OF WORKING FLUID IN A HYDRAULIC SYSTEM.
    - F. PUMP - A DEVICE WHICH CREATES THE FLOW OF HYDRAULIC FLUID. USUALLY, A PUMP.CONVERTS MECHANICAL FORCE FLUID POWER.
    - G. LINE - A TUBE, PIPE, OR HOSE FOR CONDUCTING A FLUID.
    - H. VALVE - A DEVICE WHICH CONTROLS THE PRESSURE, RATE OF FLOW, AND DIRECTION OF FLUIDS.
    - I. ACTUATOR - A DEVICE WHICH CONVERTS FLUID POWER INTO MECHANICAL FORCE AND MOTION.
    - J. CYLINDER - A DEVICE WHICH CONVERTS FLUID POWER INTO LINEAR OR ROTARY MECHANICAL FORCE AND MOTION. IT USUALLY CONSISTS OF A MOVABLE ELEMENT SUCH AS A PISTON AND PISTON ROD, PLUNGER OR RAM, OPERATING WITHIN A CYLINDER BORE.
    - K. MOTOR - A DEVICE WHICH CONVERTS FLUID POWER INTO MECHANICAL FORCE AND MOTION. IT USUALLY PROVIDES ROTARY MECHANICAL MOTION.
    - L. CIRCUIT - A SERIES OF COMPONENT PARTS CONNECTED TO EACH OTHER BY FLUID LINES OR PASSAGES: THE COMPLETE PATH OF FLOW.
2. BASIC HYDRAULIC SYSTEM.

HYDRAULIC POWERS ARE USED IN MANY INDUSTRIAL APPLICATIONS TODAY. ROBOTICS IS NO EXCEPTION. MANY OF TODAY'S INDUSTRIAL ROBOTS, ESPECIALLY THE LARGE ONES, INCORPORATE HYDRAULICS IN ONE FORM OR ANOTHER. A HYDRAULIC SYSTEM IN ROBOTICS CAN BE EITHER SELF-CONTAINED, WITHIN THE ROBOT'S BASE OR PEDESTAL, OR EXTERNALLY MOUNTED NEARBY. WHICHEVER IS THE CASE, THEY PERFORM THE SAME FUNCTION--PROVIDING THE FLUID POWER FOR THE ROBOTS.

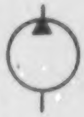
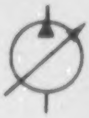
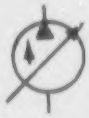
A BASIC HYDRAULIC SYSTEM IS SHOWN IN TRANSPARENCY T2-6-1. USUALLY A SYSTEM IS CAPABLE OF COMPLETING ONE OR SEVERAL OPERATIONS THAT CONSTITUTE A WORK CYCLE, AND INCLUDES THE RESERVOIR, PUMP, VALVES, CYLINDERS, MOTORS, AND SUITABLE

PLUMBING TO TRANSFER AND CONTROL FLUID POWER. A SYSTEM MAY BE COMPOSED OF SEVERAL CIRCUITS, WHICH ARE CAPABLE OF PERFORMING ONE OR MORE SPECIFIC TASKS, BUT NOT A COMPLETE CYCLE. A CIRCUIT FUNCTIONS AS PART OF A SYSTEM ACTUATOR, CONTROL VALVES, PUMP, AND OTHER BRANCH CIRCUITS ARE COMMON EXAMPLES. WE KNOW THE OIL OR FLUID RESERVOIR STORES THE HYDRAULIC FLUID USED IN THE SYSTEM. IT IS A CONSTANT RESOURCE OF POWER FOR THE SYSTEM. THE HYDRAULIC PUMP DRAWS THE HYDRAULIC FLUID OUT OF THE RESERVOIR, AND IT DISTRIBUTES THE HIGH-PRESSURE HYDRAULIC FLUID TO THE REST OF THE SYSTEM. THE HYDRAULIC CONTROL VALVES ARE USED TO CONTROL THE RATE, AMOUNT AND DIRECTION OF HYDRAULIC FLUID FLOW. THE MOTOR CONVERTS THE HIGH-PRESSURE HYDRAULIC FLUID INTO ROTARY OR LINEAR MOTION THROUGH THE USE OF ROTARY ACTUATORS OR CYLINDERS AND PISTONS TO PERFORM SOME USEFUL TASK. THE LINE, OR PIPES CARRY THE HYDRAULIC FLUID TO FLOW.

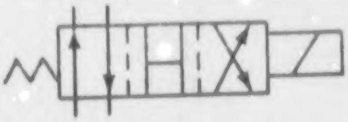
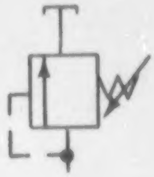
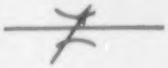
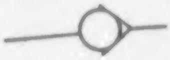
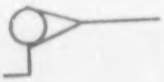
HYDRAULIC SYSTEMS MAY BE CLASSIFIED AS OPEN LOOP, CLOSED LOOP AND SERVO-SYSTEM. OPEN LOOP SYSTEMS OPERATE WITHOUT FEEDBACK FROM THE OUTPUT EXCEPT FOR THE OPERATOR. PERFORMANCE IS DETERMINED BY THE OPERATIONAL CHARACTERISTICS OF INDIVIDUAL COMPONENTS. MOST INDUSTRIAL CIRCUITS ARE OF THIS TYPE. CLOSED LOOP CIRCUITS SAMPLE THE OUTPUT AND GENERATE A PROPORTIONAL CONTROL SIGNAL THAT IS USED TO CORRECT THE INPUT COMMAND SIGNAL. IT IS WORTH NOTHING THAT UNTIL RECENTLY CLOSED LOOP HYDRASTATIC TRANSMISSIONS HAVE NOT BEEN CLOSED LOOP HYDRAULIC SYSTEMS AND THE TERM IN THIS USAGE DESCRIBES THE CLOSED FLUID FLOW PATH BETWEEN THE PUMP AND MOTOR. SERVO SYSTEMS FEEDBACK CONTROL SIGNALS TO THE INPUT COMMAND AS A RESULT OF A CHANGE IN THE MECHANICAL POSITION OF THE OUTPUT.

3. SYMBOLS USED IN HYDRAULIC SYSTEMS.

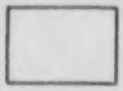
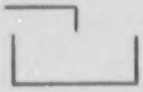
A. PUMPS

NAME		SYMBOLS
(1)	FIXED DISPLACEMENT PUMP	
(2)	VARIABLE DISPLACEMENT PUMP	
(3)	PRESSURE COMPENSATED PUMP	

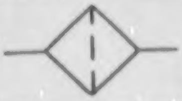
B. VALVE

(1)	DIRECTIONAL CONTROL VALVE	
(2)	PRESSURE RELIEF VALVE	
(3)	FLOW CONTROL VALVE	
(4)	CHECK VALVE	
(5)	PILOT OPERATIONAL CHECK VALVE	

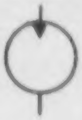
C. RESERVOIR

(1)	PRESSURIZED RESERVOIR	
(2)	VENTED RESERVOIR	

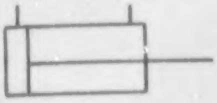
D. FILTER

(1)	FILTER	

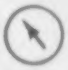
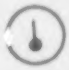
E. MOTOR

(1)	MOTOR	

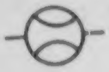
F. CYLINDER

(1)	CYLINDER	

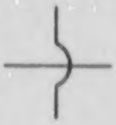
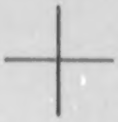
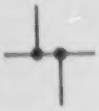
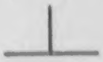
G. PRESSURE GAUGE

(1)	PRESSURE GAUGE	
(2)	TEMPERATURE GAUGE	

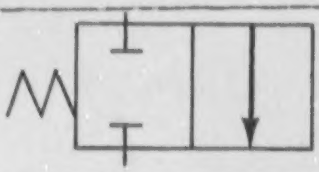
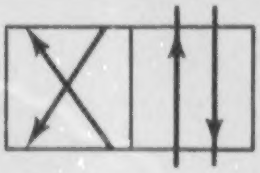
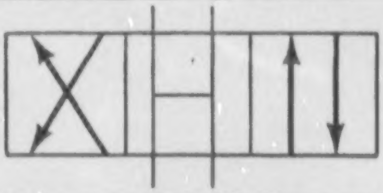
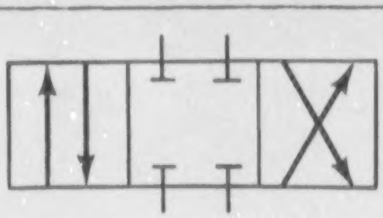
H. FLOWMETER

(1)	FLOWMETER	

I. LINE

(1)	LINES NOT JOINTED	 or 
(2)	LINES ARE JOINTED	 or 

J. CONTROL VALVES

(1)	TWO-WAY, TWO-POSITION	
(2)	FOUR-WAY, TWO-POSITION	
(3)	FOUR-WAY, THREE-POSITION OPEN-CENTER	
(4)	FOUR-WAY, THREE-WAY CLOSED-CENTER	

RESERVOIR

ALL HYDRAULIC SYSTEMS MUST HAVE THE CAPABILITY OF STORING FLUID AND THIS IS ACCOMPLISHED BY THE USE OF A RESERVOIR. THE HYDRAULIC RESERVOIR SHOULD CONTAIN ENOUGH FLUID THAT ITS WORKING LEVEL IS ALWAYS MAINTAINED DURING THE SYSTEM'S OPERATION. RESERVOIRS COME IN MANY SIZES AND SHAPES DEPENDING ON THEIR USE IN THE SYSTEM. IN LARGE HYDRAULIC SYSTEMS, THE RESERVOIR IS USUALLY A SEPARATE TANK PLACED IN AN EASILY ACCESSIBLE LOCATION; WHILE SMALLER SYSTEMS HAVE THE RESERVOIR BUILT INTO THE EQUIPMENT IT IS SERVING. THE CAPACITY OF A RESERVOIR IS GENERALLY BETWEEN TWO AND THREE TIMES THE CAPACITY OF THE HYDRAULIC PUMP. IN OTHER WORDS, A PUMP DELIVERING 10 GALLONS PER MINUTE WOULD NEED A RESERVOIR WITH A CAPACITY OF ABOUT 30 GALLONS. BESIDES THAT, IT SHOULD ALSO BE UNDERSTOOD THAT SYSTEMS BLOWING HIGH PRESSURE FLUID OVER THE RELIEF VALVE CAUSE RAPID HEAT BUILD UP, AND A PROPER AMOUNT OF FLUID SHOULD BE MAINTAINED AND CIRCULATED WITHIN THE RESERVOIR TO HELP DISSIPATE ITS HEAT. USUALLY, A RESERVOIR IS CONSTRUCTED OF WELDED STEEL PLATES WITH REMOVABLE CLEAN OUT COVERS OR DOORS.

OTHER FEATURES OF A WELL DESIGNED RESERVOIR, AS SHOWN IN FIG. 2-6-1 MAY INCLUDE THE FOLLOWING COMPONENTS:

1. BAFFLE PLATE - THE BAFFLE PLATE SEPARATES THE SYSTEM RETURN FLUID FROM THAT GOING TO THE PUMP INLET. THIS AIDS IN COOLING BY PROMOTING THE FLOW OF FLUID ALONG THE SIDE WALLS, AND ALSO HELPS TO SEPARATE WATER, ENTRAINED AIR, AND DIRT FROM THE HYDRAULIC FLUID.

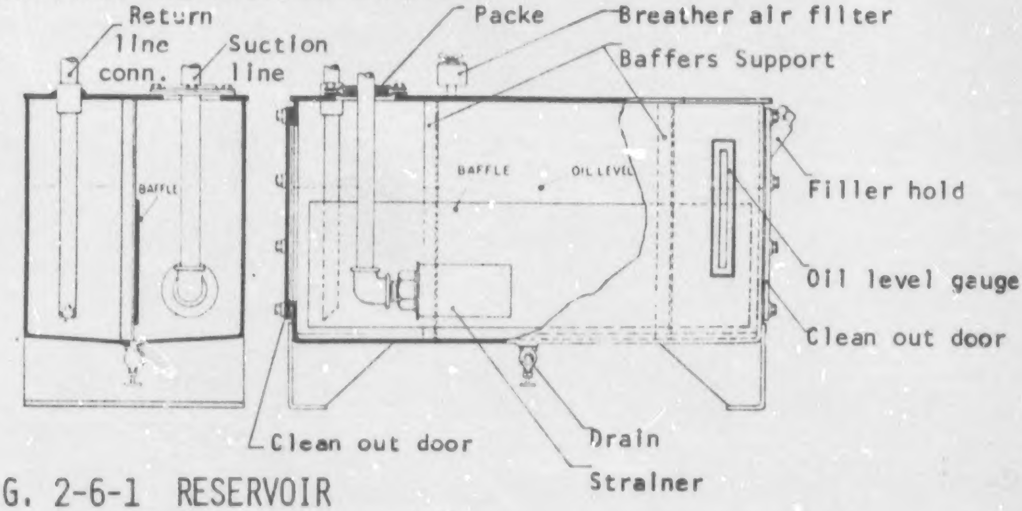

Return line conn.
Suction line
Packe
Breather air filter
Baffers Support
BAFFLE
BAFFLE
OIL LEVEL
Filler hold
Oil level gauge
Clean out door
Clean out door
Drain
Strainer

FIG. 2-6-1 RESERVOIR

2. BOTTOM DRAIN - A DRAIN CONNECTION ON THE DISHED BOTTOM OF THE RESERVOIR PROVIDES A MEANS OF DRAINING WATER AND SEDIMENT FROM THE SYSTEM. THIS IS ALSO IMPORTANT WHEN FLUID IN THE SYSTEM IS BEING CHANGED.
3. FILLER HOLD - A CAPPED HOLE FITTED WITH A FINE MESH SCREEN PREVENTS ACCIDENTAL CONTAMINATION WHEN THE RESERVOIR IS BEING REPLENISHED TO PROPER OPERATING LEVEL.
4. BREATHER AIR FILTER - THE AIR FILTER MUST BE OF ADEQUATE SIZE AND EQUIPPED WITH A FILTER ELEMENT SUITABLE TO THE LOCAL ATMOSPHERIC CONDITIONS UNDER WHICH IT MUST WORK. SINCE THE FLUID LEVEL IN THE RESERVOIR MUST RISE AND FALL AS THE CYLINDERS STROKE, AIR COMES AND GOES THROUGH THE BREATHER. THE FILTER ELEMENT MUST BE KEPT CLEAN TO ALLOW ATMOSPHERIC PRESSURE TO BE IN CONTACT WITH THE LIQUID AT ALL TIMES.
5. RETURN LINE - THE RETURN LINE SHOULD BE CUT ON AN ANGLE BEFORE IT IS FITTED INTO THE RESERVOIR. THIS PREVENTS ANY RESTRICTION ON THE RETURNING FLUID BY JAMMING THE END OF THE RETURN PIPE AGAINST THE BOTTOM OF THE RESERVOIR. THE SIZE OF THE RETURN LINE SHOULD BE LARGE ENOUGH TO PREVENT EXCESSIVE BACK PRESSURES IN THE SYSTEM (USUALLY LESS THAN 30 PSI).
6. PUMP INLET LINE - THE PUMP INLET LINE SHOULD BE LARGE ENOUGH TO ASSURE SATISFACTION OF THE INLET REQUIREMENTS OF THE HYDRAULIC PUMP TO PREVENT CAVITATION. A SLIP JOINT OR OTHER MEANS SHOULD BE EMPLOYED TO FACILITATE THE COMPLETE REMOVAL OF THE INLET LINE AND STRAINER TO PERMIT REGULAR INSPECTION OR CLEANING OF THE STRAINER ELEMENT.
7. DRAIN LINE - AN EXTRA DRAIN LINE MUST BE FITTED INTO THE RESERVOIR WHEN BACK PRESSURES IN THE RETURN LINE ARE TOO GREAT. THE DRAIN LINE WOULD BE USED EXCLUSIVELY TO ALLOW THE FREE DRAIN OF ANY COMPONENTS FITTED WITH EXTERNAL DRAIN CONNECTIONS.
8. SIGHT GLASS - THE SIGHT GLASS PROVIDES A VISUAL CHECK ON THE FLUID LEVEL. PROPER FLUID OPERATING LEVELS MUST BE MAINTAINED.

USUALLY A RESERVOIR HAS THE FUNCTIONS AS FOLLOW:

A. PROVIDES FLUID TO REPLACE SYSTEM LEAKAGE.
B. CONTAINS EXCESS FLUID RESULTING FROM SYSTEM VOLUME CHANGES.
C. HELPS TO COOL SYSTEM.
D. HELPS TO SEPARATE DIRT AND AIR FROM FLUID.

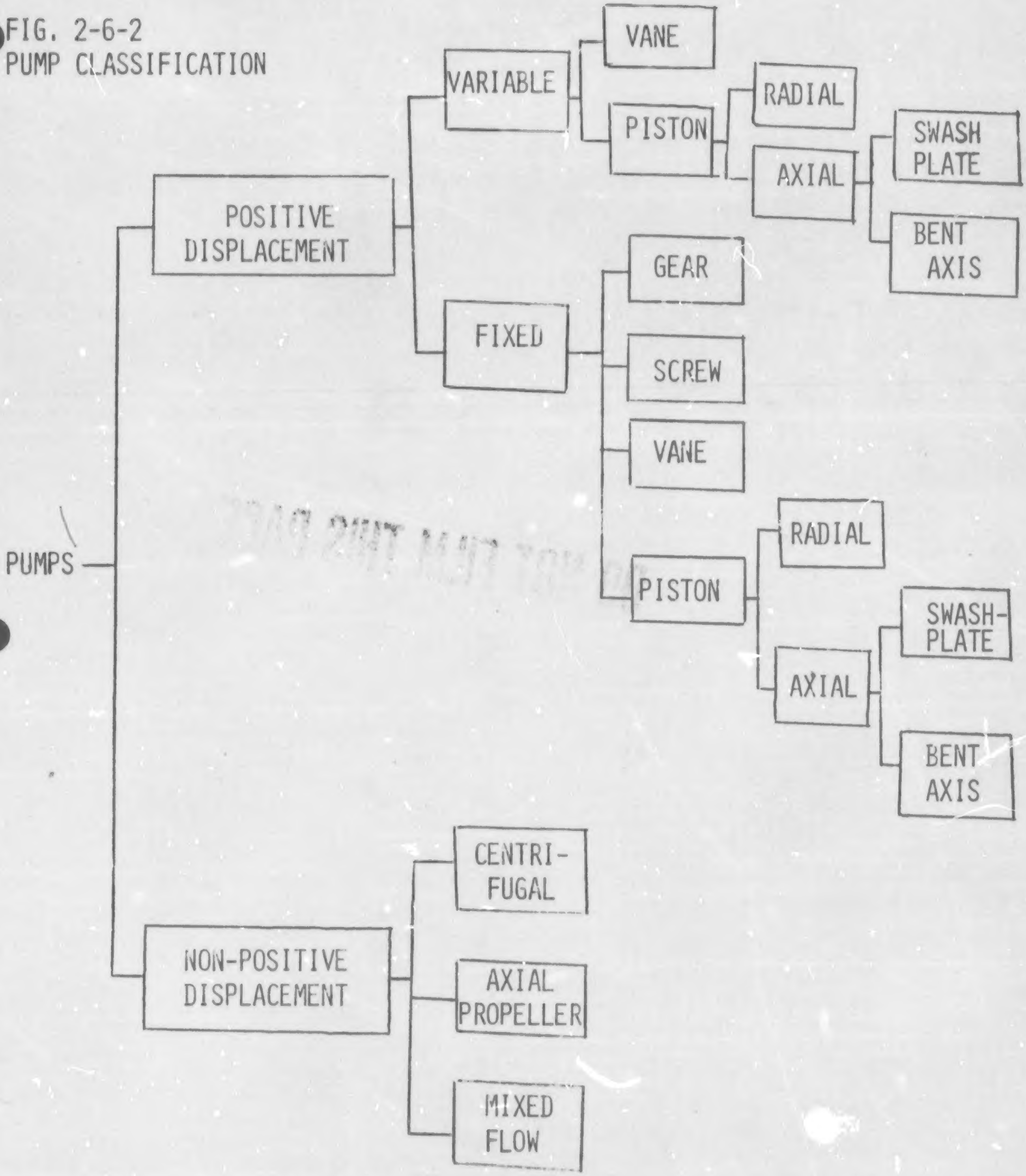
HYDRAULIC PUMPS

THE PUMP COULD BE REFERRED TO AS THE HEART OF THE HYDRAULIC SYSTEM, AS IT IS PROBABLY THE MOST IMPORTANT COMPONENT IN THE SYSTEM. A HYDRAULIC PUMP IS DEFINED AS A DEVICE WHICH CONVERTS MECHANICAL FORCE AND MOTION INTO FLUID POWER.

HYDRAULIC PUMPS RAISE THE ENERGY LEVEL OF THE FLUID. THE PUMPING ACTION INVOLVES THE TRANSFER OF FLUID FROM THE LOW ENERGY SUPPLY IN THE RESERVOIR, TO THE CLOSED HYDRAULIC SYSTEM WHERE HIGH ENERGY FLUID IS USED TO ACCOMPLISH WORK. FOR THIS REQUIREMENT, TRY TO THINK OF THE PUMP ACTING AS A COMPRESSOR, BUT IT IS NOT, BECAUSE THE PURPOSE OF THE PUMP IS NOT TO COMPRESS IT, IT IS TO CREATE A FORCE. IN ORDER TO DETERMINE A CORRECT PUMP FOR A GIVEN APPLICATION, THE FLUID PRESSURE, FLOW RATES, AVAILABLE DRIVE SPEEDS AND POWER, EFFICIENCIES, COSTS, SIZE, MAINTENANCE, AND OTHER PUMP AND SYSTEM OPERATIONAL CHARACTERISTICS SHOULD BE CONSIDERED.

1. TYPES OF PUMPS. THE CLASSIFICATIONS OF PUMPS ARE SHOWN IN FIGURE 2-6-2

FIG. 2-6-2
PUMP CLASSIFICATION


PUMPS
POSITIVE DISPLACEMENT
VARIABLE
VANE
PISTON
RADIAL
AXIAL
SWASH PLATE
BENT AXIS
FIXED
GEAR
SCREW
VANE
PISTON
RADIAL
AXIAL
SWASH-PLATE
BENT AXIS
NON-POSITIVE DISPLACEMENT
CENTRI-FUGAL
AXIAL PROPELLER
MIXED FLOW

A. POSITIVE DISPLACEMENT PUMPS:

POSITIVE DISPLACEMENT PUMPS TRANSFER A CONSTANT AMOUNT OF FLUID FOR EACH CYCLE OF OPERATION. A PUMP WHOSE INLET IS SEALED FROM THE OUTLET, WILL DELIVER FLUID ANY TIME THE INLET IS KEPT SUPPLIED AND THE PUMP IS DRIVEN.

B. NON-POSITIVE DISPLACEMENT PUMPS:

A PUMP WHOSE INLET AND OUTLET ARE HYDRAULICALLY CONNECTED SO THAT THE FLUID CAN RECIRCULATE IN THE PUMP WHEN PRESSURE BUILDS UP.

C. KINDS OF POSITIVE DISPLACEMENT PUMP:

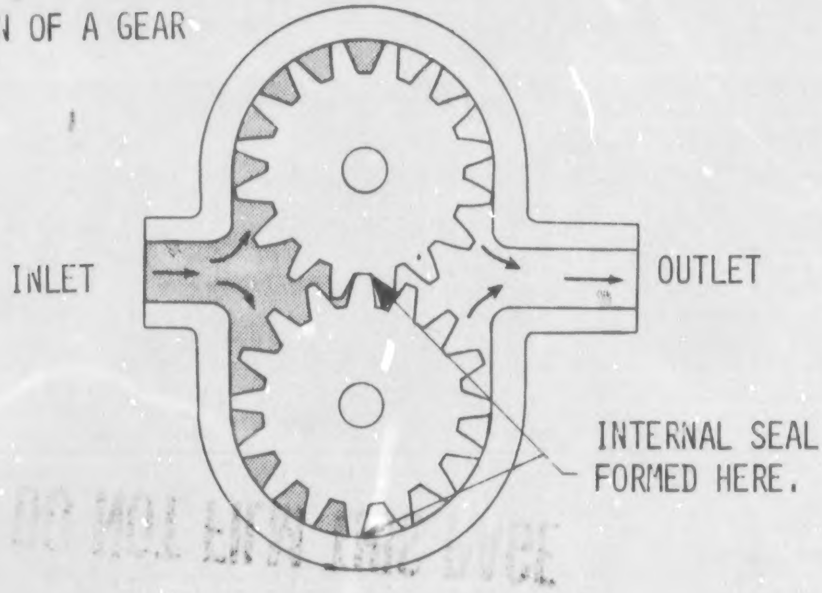
POSITIVE DISPLACEMENT PUMPS USUALLY TRANSFER A CONSTANT AMOUNT OF FLUID FOR EACH CYCLE OF OPERATION. IF THIS INTERNAL PUMP VOLUME CANNOT BE ADJUSTED, THE PUMP IS CONSIDERED TO HAVE A FIXED DISPLACEMENT. IF THE TRANSFER MECHANISM AND INTERNAL VOLUME OF THE PUMP ARE ADJUSTABLE, THE PUMP IS CONSIDERED TO BE A VARIABLE VOLUME DISPLACEMENT PUMP.

FOR THE POSITIVE DISPLACEMENT USAGE, TRANSFER FLUID FROM THE LOW PRESSURE INLET PART TO THE HIGH PRESSURE OUTLET PART THROUGH THE MOTION OF A ROTATING DRIVE SHAFT AND INTERNAL TRANSFER MECHANISM. THE GEAR, VANE, SCREW AND SOME PISTON PUMPS ARE A PART OF THIS CLASSIFICATION.

1. GEAR PUMP.

THE GEAR PUMP CONSISTS OF TWO OR MORE GEARS. THEY ARE THE DRIVE GEAR, THE GEAR OF DIRECTLY DRIVING BY ENGINE OR MOTOR, AND THE DRIVEN GEAR WHICH IS DRIVEN BY THE DRIVER GEAR. AS THE GEARS PASS THE INLET OF THE PUMP, THE SPACE BETWEEN THE GEAR TEETH FILLS WITH FLUID, THEN THE ROTATION OF THE GEARS CARRIES THE FLUID AROUND THE OUTSIDE PERIMETER OF THE GEARS TO THE OUTLET, AS SHOWN IN FIG. 2-6-3.

FIG. 2-6-3
OPERATION OF A GEAR PUMP.



2. VANE PUMPS.

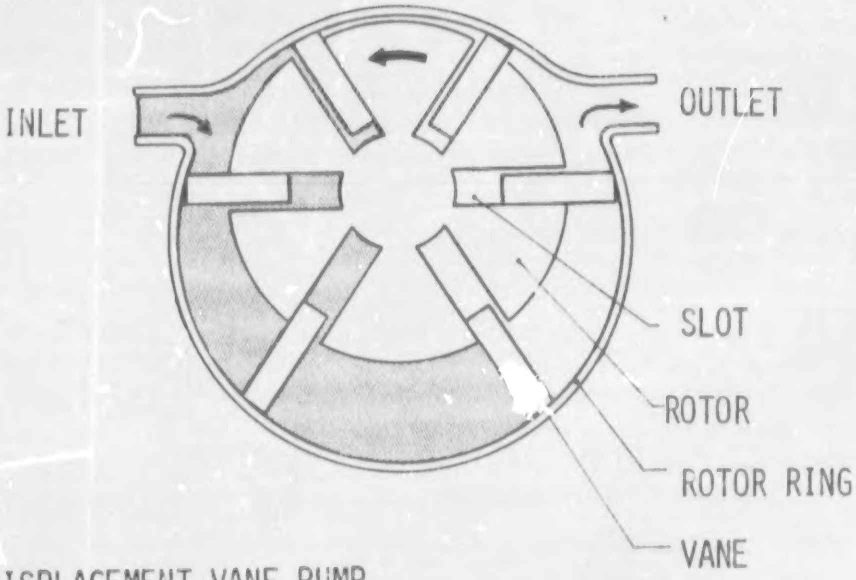
VANE PUMPS ARE CLASSIFIED AS FIXED OR VARIABLE DISPLACEMENT AND UNBALANCED OR BALANCED DESIGN. USUALLY THREE PUMP COMBINATIONS ARE AVAILABLE:

--FIXED DISPLACEMENT, UNBALANCED DESIGN
--FIXED DISPLACEMENT, BALANCED DESIGN (TWO SETS OF INLET AND OUTLET PARTS ON THE OPPOSITE SIDE.)
--VARIABLE DISPLACEMENT, UNBALANCED DESIGN

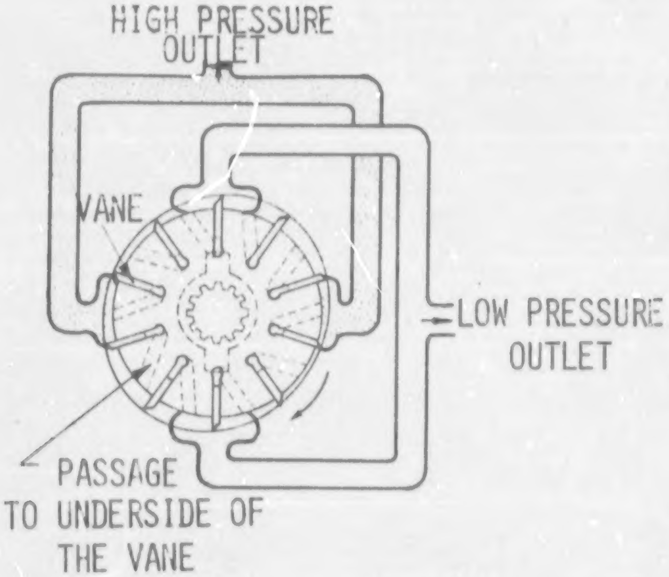
THE ESSENTIAL COMPONENTS OF THE VANE PUMP INCLUDE THE INLET AND OUTLET PORTS, SLIDING VANES, DRIVEN ROTOR AND STATIONARY CAM RING. IN A FIXED DISPLACEMENT VANE PUMP, THE VANES ARE INSTALLED INTO THE SLOTS IN THE ROTOR AND ARE FREE TO MOVE IN A RADIAL DIRECTION, THAT IS, TOWARD OR AWAY FROM THE CENTER OF THE ROTOR. AS THE ROTOR ROTATES, THE VANES ARE FORCED OUTWARD TO CONTACT THE SURFACE OF THE CIRCULAR CHAMBER. THE ROTOR IS INSTALLED OFFSET IN THE CIRCULAR CHAMBER. WHEN THE ROTOR ROTATES A VANE PAST THE INLET PORT, A VOLUME OF FLUID IS TRAPPED BETWEEN TWO VANES. SINCE THE ROTOR IS INSTALLED OFFSET IN THE CIRCULAR CHAMBER, THE VOLUME CONTAINED BETWEEN TWO ROTORS BECOMES SMALLER AND THE TRAPPED FLUID IS EXPELLED FROM THE OUTLET.

VARIABLE DISPLACEMENT VANE PUMP CAN BE CHANGED BY CHANGING THE POSITION OF THE ROTOR IN THE CIRCULAR CHAMBER AS SHOWN IN FIGURE 2-6-4.

FIG. 2-6-4
UNBALANCED VANE PUMP


INLET
OUTLET
SLOT
ROTOR
ROTOR RING
VANE

FIXED DISPLACEMENT VANE PUMP


HIGH PRESSURE
OUTLET
VANE
LOW PRESSURE
OUTLET
PASSAGE
TO UNDERSIDE OF
THE VANE

3. SCREW PUMPS.

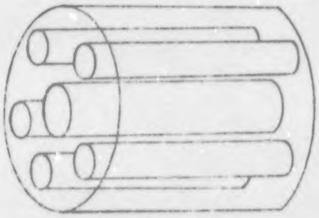
THERE ARE THREE TYPES OF SCREW PUMPS WHICH ARE COMMERCIALLY AVAILABLE. THESE THREE TYPES ARE THE SINGLE-SCREW, THE TWO-SCREW, AND THE THREE SCREW PUMPS. A SINGLE SCREW PUMP CONSISTS OF A SPIRALED ROTOR WHICH ROTATES ECCENTRICALLY IN AN INTERNAL ROTATOR. A TWO SCREW PUMP CONSISTS OF TWO PARALLEL ROTORS WITH INTER-MESHING THREADS ROTATING IN A CLOSELY MACHINED HOUSING. THESE PUMPS USE EXTERNAL OR INTERNAL TIMING GEARS. A THREE-SCREW PUMP CONSISTS OF A CENTRAL DRIVE ROTOR WITH TWO MESHING IDLER ROTORS. THE THREE ROTORS ARE SURROUNDED BY A CLOSELY MACHINED HOUSING.

THE FLOW THROUGH A SCREW PUMP IS AXIAL AND IN THE DIRECTION OF THE POWER ROTOR. THE VOLUME DELIVERED BY SCREW PUMPS IS EASY TO MAINTAIN, BECAUSE THE FLUID DOES NOT ROTATE BUT MOVE LINEARLY.

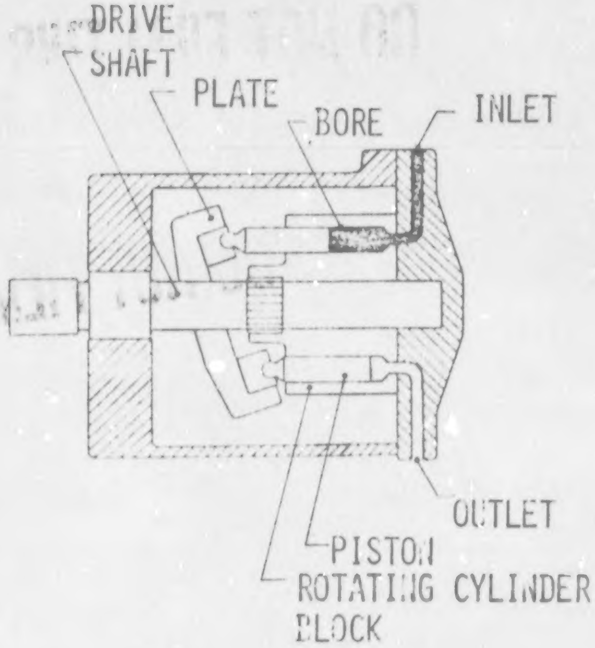
4. PISTON PUMPS.

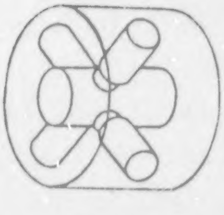
PISTON-TYPE PUMPS ARE THE OLDEST FORM OF HYDRAULIC PUMPS. THERE ARE TWO TYPES OF THEM AND THEY ARE THE AXIAL AND RADIAL PISTON PUMPS. THE AXIAL PISTON PUMPS ARE PUMPS IN WHICH THEIR PISTONS PARALLEL THE AXIS OF THE PUMP. RADIAL PISTON PUMPS ARE THOSE IN WHICH THEIR PISTONS ARE PERPENDICULAR TO THE AXIS OF THE PUMP, AS SHOWN IN FIGURE 2-6-5. AXIAL PISTON PUMPS ARE FURTHER CLASSIFIED AS IN-LINE OR BENT AXIS DRIVE PISTON PUMPS, AS SHOWN IN FIGURE 2-6-6.

FIG. 2-6-5



Axial Piston Pump


DRIVE
SHAFT
PLATE
BORE
INLET
OUTLET
PISTON
ROTATING CYLINDER
BLOCK



Radial Piston Pump

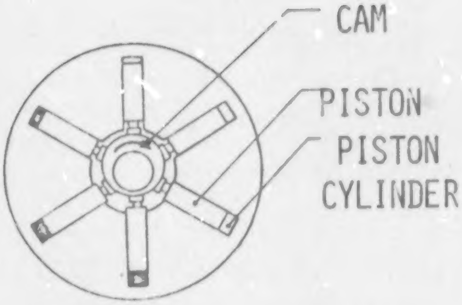
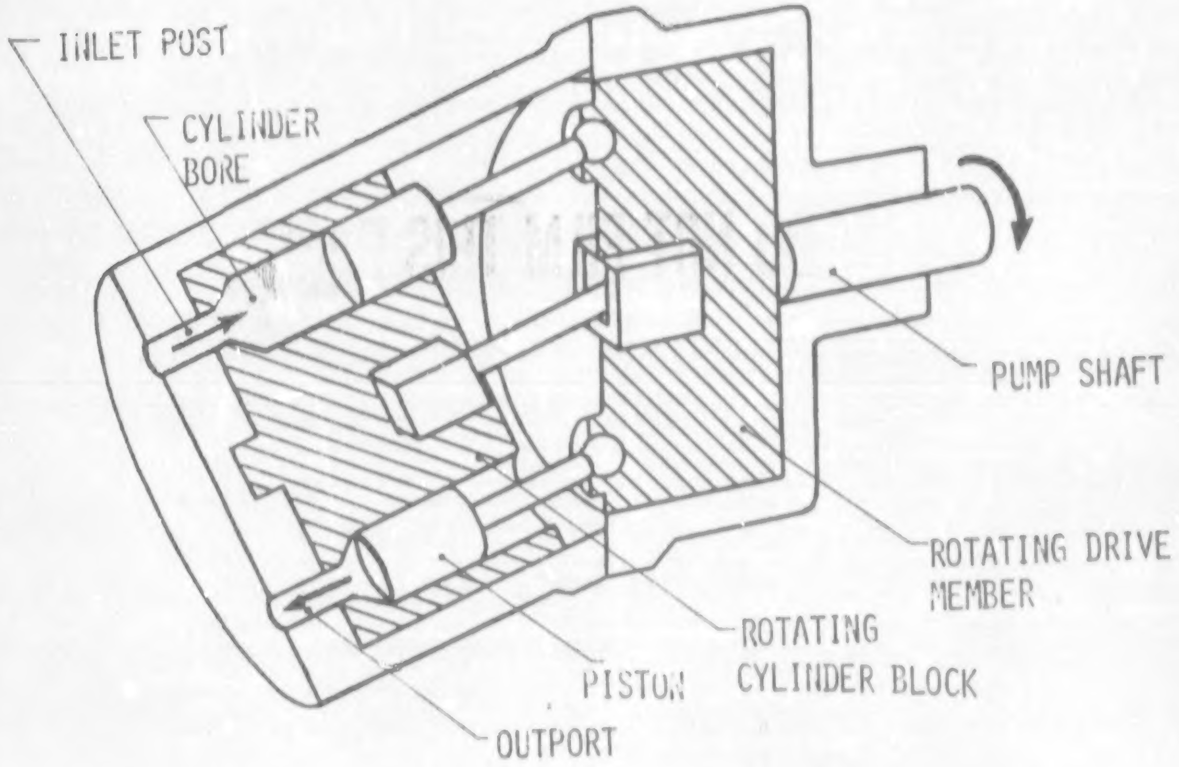

CAM
PISTON
PISTON
CYLINDER

FIG. 2-6-6


INLET POST
CYLINDER BORE
PUMP SHAFT
ROTATING DRIVE MEMBER
ROTATING CYLINDER BLOCK
PISTON
OUTPORT

INLINE AND BENT AXIS DRIVE PISTON PUMP

2. CALCULATION FORMULA OF PUMPS:

   A. PUMP DISPLACEMENT-

$$D = \frac{231Q}{N}$$

WHERE:

D = DISPLACEMENT IN IN^3/REV.

Q = PUMP OUTLET FLOW RATE IN GALLONS PER MINUTE (GPM)

N = PUMP SPEED IN R.P.M.

(EXAMPLE):

A PUMP WHICH HAS AN OUTLET FLOW OF 20 GPM AT 1800 R.P.M. HAS A DISPLACEMENT OF 2.56 IN^3/REV.

$$D = \frac{231 \times 20}{1800} = 2.56\ IN^3/REV.$$

B. PUMP FLOW RATE

$$Q = \frac{N \times D}{231}$$

(EXAMPLE):

A 2.56 IN^3/REV. PUMP OPERATING AT 2400 R.P.M. HAS A FLOW RATE OF 26.6 GPM.

$$Q = \frac{2400 \times 2.56}{231} = 26.6\ GPM$$

C. PUMP POWER

-OUTPUT POWER

$$POWER = \frac{P \times Q}{1714}$$

WHERE: POWER = OUTPUT POWER IN HORSEPOWER
P = OUTLET PRESSURE IN PSI
Q = OUTLET FLOW IN GPM

(EXAMPLE):

A PUMP OPERATING WITH 20 GPM FLOW AND 3000 PSI OUTLET PRESSURE HAS OUTPUT POWER OF 25 HP

$$POWER = \frac{P \times Q}{1714} = \frac{3000 \times 20}{1714} = 35\ HP$$

2. INPUT POWER.

$$\text{POWER} = \frac{\text{N} \times \text{TORQUE}}{5252}$$

WHERE: POWER = INPUT POWER IN HORSEPOWER
TORQUE = INPUT SHAFT TORQUE IN FT/LBS
N = SPEED IN RPM

(EXAMPLE):

A PUMP OPERATING AT 2400 RPM WITH A SHAFT TORQUE OF 70 FT/LBS. WHAT IS ITS INPUT POWER?

$$\text{POWER} = \frac{\text{N} \times \text{TORQUE}}{5252} = \frac{2400 \times 70}{5252} = 32 \text{ (HP)}$$

THE PUMP NEEDS 32 HP INPUT POWER FOR OPERATING.

D. VOLUMETRIC EFFICIENCY

FORMULA:

$$\text{VOLUMETRIC EFF.} = \frac{\text{ACTUAL FLOW RATE}}{\text{THEORETICAL FLOW RATE}}$$

(EXAMPLE):

THE OUTLET FLOW RATE OF A 2.56 IN^3/REV. PUMP OPERATING AT 2400 RPM IS MEASURED TO BE 22.5 GALLONS PER MINUTE (GPM). WHAT'S THE VOLUMETRIC EFFICIENCY OF IT?

$$\text{THEORETICAL FLOW RATE} = \frac{2 \times \text{D}}{231} = \frac{2400 \times 2.56}{231} = 26.6 \text{ (GPM)}$$

$$\text{VOLUMETRIC EFF.} = \frac{22.5 \text{ (GPM)}}{26.6 \text{ (GPM)}} = 0.846 = 84.6\%$$

3. COMMON CAUSES OF HYDRAULIC PUMP FAILURE:
   A. CONTAMINATED FLUID.

      CONTAMINATION INCLUDES NOT ONLY SOLID PARTICLES, BUT ALSO OTHER CONTAMINANTS SUCH AS WATER AND AIR.

   B. IMPROPER FLUID.

      THE INCORRECT FLUID MAY RESULT IN PUMP FAILURE IN A VERY SHORT TIME. THE FLUID MUST HAVE THE CORRECT VISCOSITY PROPERTIES, TEMPERATURE RANGE, AND ADDITIVES.

   C. IMPROPER OPERATING PROCEDURES.

      CONTINUOUS OPERATION AT THE PUMP'S MAXIMUM LIMITS OR EXCEEDING ITS LIMITS CAN GREATLY REDUCE THE PUMP LIFE.

   D. CAVITATION.
   E. IMPROPER PUMP MAINTENANCE.

VALVES

GENERALLY SPEAKING, THE HYDRAULIC VALVES ARE USED TO CONTROL THE PRESSURE, RATE OF FLOW, AND DIRECTION OF FLUIDS IN ACCORDANCE WITH BASIC PRINCIPLES OF FLOW.

PRESSURE CONTROL VALVES ARE USED TO LIMIT AND REDUCE PRESSURE, SEQUENCE HYDRAULIC OPERATIONS AND COUNTERBALANCE EXTERNAL LOADS.

FLOW CONTROL VALVES ARE USED TO VARY THE FLUID FLOW RATE IN FLUID PASSAGES WHICH MAY BE FIXED, VARIABLE, OR FLOW AND PRESSURE COMPENSATED.

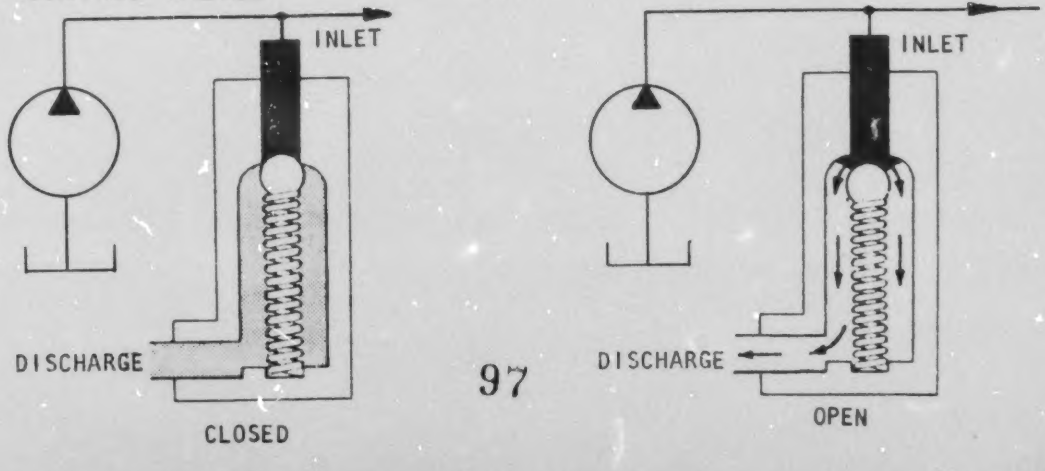
DIRECTION CONTROL VALVES ARE USED TO CHECK, DIVERT, SHUTTLE, PROPORTION AND BY OTHER MEANS MANAGE THE FLOW OF FLUID IN ONE, TWO, THREE, OR MORE WAYS. PRESSURE AND FLOW COMPENSATION ARE ALSO COMMONLY INCLUDED IN DIRECTIONAL CONTROL VALVES.

IN A HYDRAULIC SYSTEM, THE VALVES ARE A VERY IMPORTANT COMPONENTS FOR PROVIDING FLEXABILITY IN ITS OPERATION SYSTEM. THE HYDRAULIC VALVES ARE RANGING FROM VERY SIMPLE TO EXTREMELY COMPLEX IN DESIGN AND FUNCTIONS.

1. PRESSURE CONTROL VALVES:

THERE ARE TWO KINDS OF PRESSURE CONTROL VALVES USED IN HYDRAULIC SYSTEMS; RELIEF VALVES AND PRESSURE REDUCING VALVES. USUALLY A PRESSURE RELIEF CONTROL VALVE IS CONNECTED BETWEEN THE PUMP OUTLET AND THE RESERVOIR AND IS NORMALLY CLOSED, AS SHOWN IN FIGURE 2-6-7. ITS PURPOSE IS TO LIMIT THE SYSTEM PRESSURE TO SOME PREDETERMINED LEVEL BY DIVERTING SOME OR ALL THE PUMP'S OUTPUT TO THE RESERVOIR WHEN THAT PRESSURE LEVEL HAS BEEN REACHED.

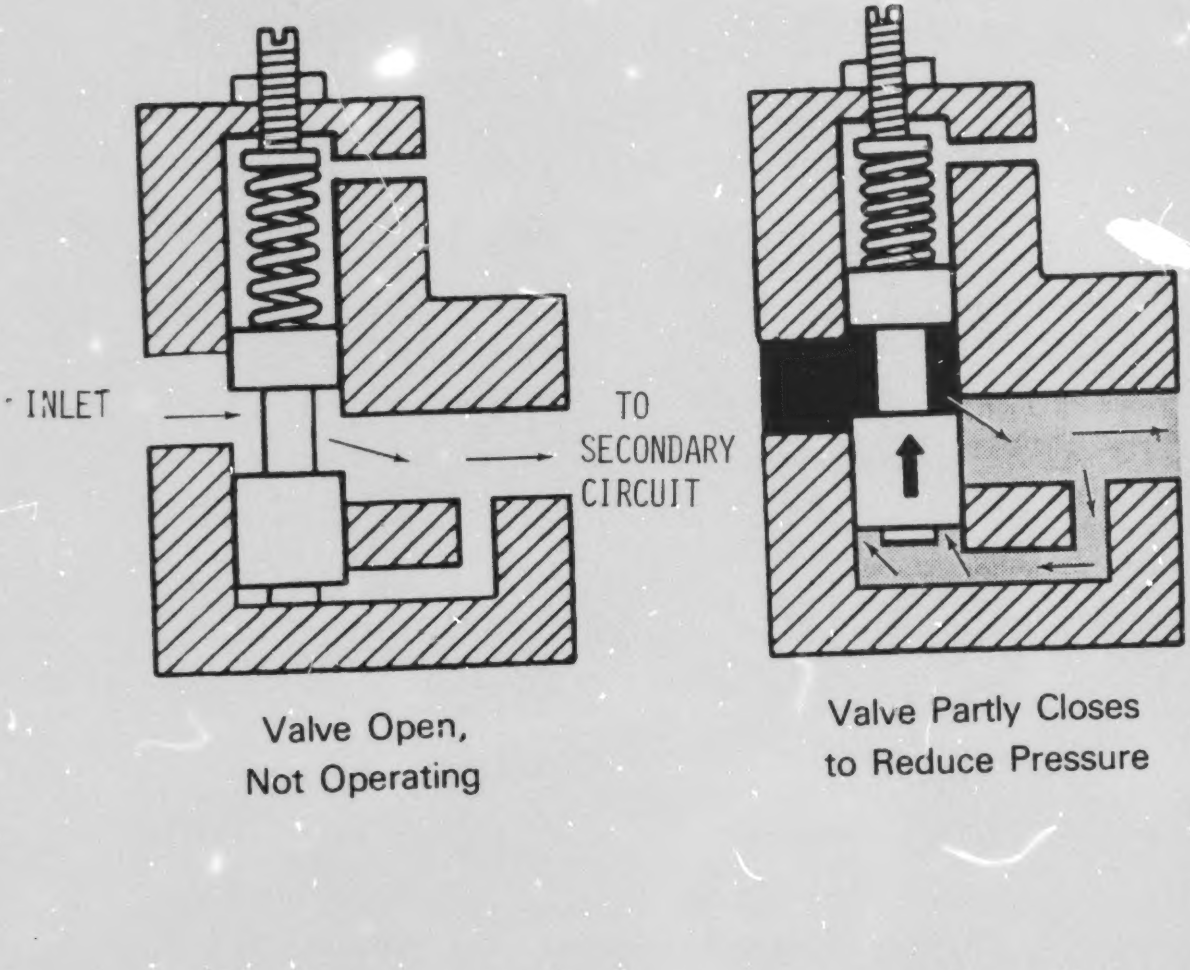
FIG. 2-6-7
RELIEF CONTROL VALVES



WHEN THE FLUID PRESSURE EXCEEDS THE SETTING OF THE ADJUSTABLE SPRING FORCE, DUE TO EXCESSIVE PUMP OUTPUT OR SYSTEM OVERLOAD, THE BALL OR POPPET IS FORCED OFF ITS SEAT, ALLOWING SOME OR ALL OF THE FLUID TO FLOW TO THE RESERVOIR. WHEN THE EXCESSIVE PRESSURE IS REMOVED, THE BALL OR POPPET WILL RETURN TO ITS SEAT AND NORMAL OPERATION WILL RESUME.

SHOWN IN FIGURE 2-6-8 IS A PRESSURE REDUCING VALVE. IT IS USED TO LIMIT ITS OUTLET PRESSURE. USUALLY THESE VALVES ARE AVAILABLE IN VARIOUS OPERATING RANGES AND ARE ADJUSTABLE. THEIR APPLICATION IS IMPORTANT WHERE LIMITED PRESSURE MUST BE CONTROLLED.

FIG. 2-6-8
PRESSURE REDUCING VALVE



Valve Open,
Not Operating

Valve Partly Closes
to Reduce Pressure

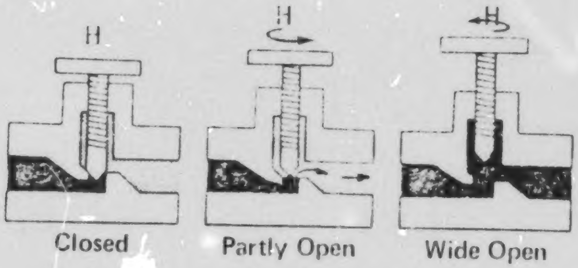
REDUCING VALVES ARE ALSO USED FOR THE OPERATION OF BRANCH CIRCUITS: WHERE PRESSURE MAY VARY FROM THE MAIN SYSTEM PRESSURES. THE PRESSURE REDUCING VALVE IS NORMALLY AN OPEN-TYPE VALVE. A FREE FLOW PASSAGE IS PROVIDED THROUGH THE VALVE FROM INLET TO SECONDARY OUTLET UNTIL A SIGNAL FROM THE OUTLET SIDE TENDS TO THROTTLE THE PASSAGE THROUGH THE VALVE. THE VALVE OPERATES ON THE PRINCIPLE THAT PILOT PRESSURE FROM THE CONTROLLED PRESSURE SIDE OPPOSES AN ADJUSTABLE BIAS SPRING NORMALLY HOLDING THE VALVE OPEN. WHEN THE TWO FORCES ARE EQUAL, THE PRESSURE DOWNSTREAM IS CONTROLLED AT THE VALVE SETTING. THUS, IT CAN BE VISUALIZED THAT IF THE SPRING HAS GREATER FORCE, THE VALVE OPENS WIDER: IF THE CONTROLLED PRESSURE HAS GREATER FORCE, THE VALVE MOVES TOWARD THE SPRING AND THROTTLES THE FLOW.

2. FLOW CONTROL VALVES.

A FLOW CONTROL VALVE HAS THE PRIMARY FUNCTION OF CONTROLLING THE RATE OF FLOW. BASICALLY, THE AMOUNT OF FLUID DELIVERED TO A GIVEN LOAD OF A SYSTEM DETERMINES ITS OPERATIONAL SPEED. TO REGULATE THIS SPEED, FLOW OR VOLUME CONTROL DEVICES ARE USED.

THERE ARE THREE TYPES OF FLOW CONTROL VALVES: NEEDLE VALVE, COMPENSATED FLOW CONTROL VALVE AND FLOW DIVIDER. THE FIRST ONE IS, AS SHOWN IN FIG. 2-6-9, A NEEDLE VALVE. IT SERVES AS AN ADJUSTABLE MEANS OF REGULATING THE FLOW TO A SECONDARY CIRCUIT BY RESTRICTING THE FLUID FLOW. AS THE KNOB ON THE NEEDLE VALVE IS TURNED A NEEDLE IS LOWERED INTO THE FLUID STREAM. WHEN THE

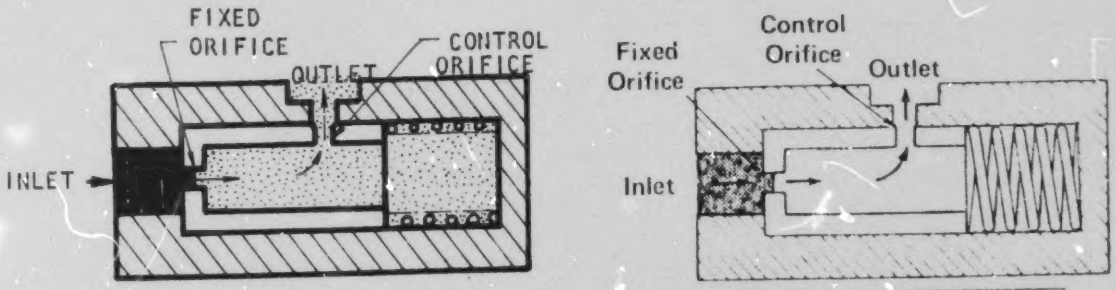
FIG. 2-6-9
NEEDLE VALVE



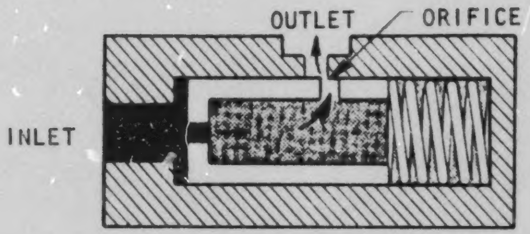
KNOT IS TURNED TO ITS EXTREME POSITION THE NEEDLE CLOSES ONTO A SEAT RESTRICTING THE FLUID FLOW.

THE SECOND ONE, AS SHOWN IN FIGURE 2-6-10, IS THE COMPENSATED FLOW CONTROL VALVE. THE FLOW GOES THROUGH A FIXED ORIFICE IN THE INLET AND CAUSES A PRESSURE DROP. THE FULL INLET PRESSURE IS APPLIED TO THE INLET SIDE AND A REDUCED PRESSURE IS APPLIED TO THE SPRING SIDE OF THE SPOOL. IF THE FORCE CREATED BY THE PRESSURE DIFFERENCES IS GREATER THAN THE SPRING FORCE, THE VALVE SPOOL MOVES TO CLOSE THE OUTLET ORIFICE AND THUS REDUCES THE FLOW RATE. USUALLY, THE SYSTEM FUNCTIONS TO MAINTAIN A CONSTANT PRESSURE DROP ACROSS THE INLET ORIFICE, AND IF THIS PRESSURE DROP IS CONTROLLED, THEN THE FLOW WILL BE CONTROLLED.

FIG. 2-9-10
COMPENSATED FLOW CONTROL VALVE


FIXED ORIFICE
CONTROL ORIFICE
OUTLET
INLET
Fixed Orifice
Control Orifice
Outlet
Inlet

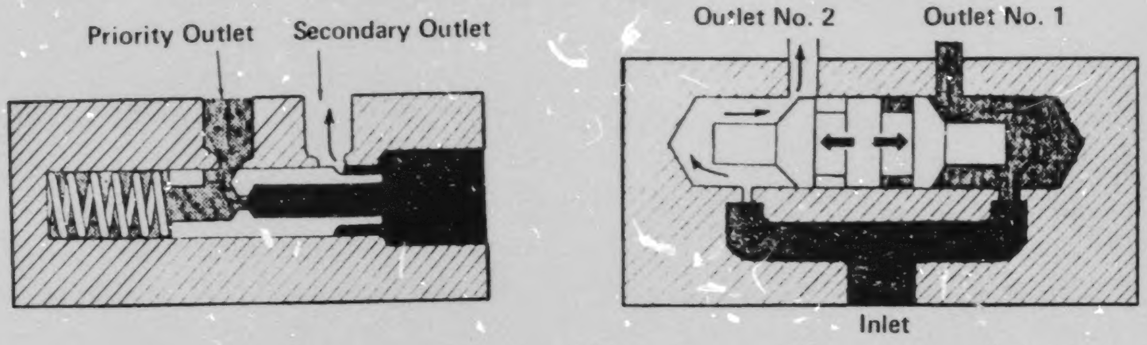
Control Orifice Fully Open


OUTLET
ORIFICE
INLET

CONTROL ORIFICE PARTLY CLOSED

THE LAST ONE IS THE FLOW DIVIDER. THEY ARE DIVIDED INTO TWO KINDS: PRIORITY FLOW DIVIDER AND PROPORTIONAL FLOW DIVIDER. A PRIORITY FLOW DIVIDER IS USED IN CIRCUITS WHERE FLOW MUST BE MAINTAINED TO SOME PART OF THE CIRCUIT. AS SHOWN IN FIGURE 2-6-11 ARE THE FLOW DIVIDERS.

FIG. 2-6-11
FLOW DIVIDER



A PRIORITY FLOW DIVIDER FUNCTIONS TO SUPPLY A REGULATED FLOW TO THE PRIORITY OUTPUT, AND THE REMAINING FLOW IS ROUTED TO THE SECONDARY CIRCUIT. AS THE FLOW DIVIDER SPOOL SLIDES IN ITS BORE, ONE OUTLET IS OPENED WIDER WHEN THE OTHER IS CLOSED OFF. FLUID FROM THE INLET IS METERED THROUGH AN ORIFICE IN THE SPOOL, CAUSING A PRESSURE DROP WHICH TENDS TO DISPLACE THE SPOOL TO CLOSE OFF THE PRIORITY OUTLET, AND THIS DISPLACEMENT IS RESISTED BY THE SPRING. USUALLY THE SPOOL WILL POSITION TO MAINTAIN A CONSTANT PRESSURE DROP ACROSS THE SPOOL ORIFICE AND THUS A CONSTANT FLOW TO THE PRIORITY OUTLET. THE SECONDARY OUTLET WILL BE OPENED TO RECEIVE THE REMAINING FLOW THAT IS AVAILABLE.

A PROPORTION FLOW DIVIDER IS USED TO DIVIDE THE FLOW INTO TWO CIRCUITS. USUALLY THE FLUID FROM INLET FLOWS THROUGH TWO ORIFICES (ONE ON EACH SIDE OF THE SPOOL) CAUSING A PRESSURE DROP ACROSS THE TWO ORIFICES. THE RESULTING PRESSURE IS APPLIED TO EACH SIDE OF THE SPOOL. IF THE PRESSURE DROP ACROSS THE TWO ORIFICES IS NOT EQUAL, THE SPOOL SHIFTS AND CHANGES THE RESTRICTION AT THE OUTLET ORIFICE. THE RATIO OF THE FLOW

FROM THE TWO OUTLETS IS SET BY THE SIZE OF THE TWO INLET ORIFICES. EQUAL ORIFICE SIZE RESULT IN EQUAL FLOW RATES, SO THE VALVE FUNCTIONS TO MAINTAIN EQUAL PRESSURE DROP ACROSS THE INLET ORIFICES.

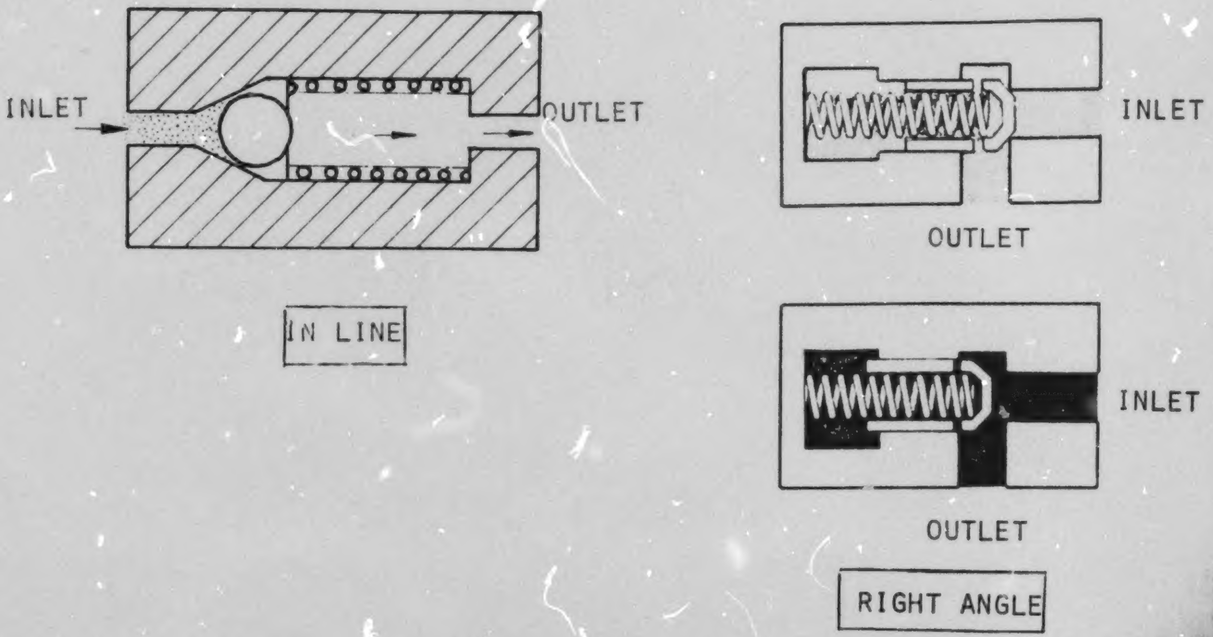
3. DIRECTIONAL CONTROL VALVES:

DIRECTIONAL CONTROL VALVES MANAGE THE FLOW PATH OF THE FLUID IN THE SYSTEM. THE FUNCTION TO STOP, START, CHECK, DIVERT, SHUTTLE, DIVIDE PROPORTIONALLY AND BY OTHER MEANS DIRECT THE FLOW OF FLUID. THE MORE COMMON DIRECTIONAL CONTROL VALVES ARE USUALLY REFERRED TO BY THE NUMBER OF FLOW PATHS, I.E., ONE, TWO, THREE, OR FOUR-WAY VALVES. THESE VALVES MAY BE ACTUATED MANUALLY, MECHANICALLY, ELECTRICALLY OR BY PRESSURE.

A. ONE WAY VALVES.

THE SIMPLEST DIRECTIONAL VALVES ARE THE ONE WAY VALVES OR CHECK VALVES. THIS KIND OF VALVE ALLOWS FLOW IN ONE DIRECTION THROUGH THE VALVE AND IS USUALLY DESIGNED FOR IN LINE OR RIGHT ANGLE CONNECTIONS AS SHOWN IN FIGURE 2-6-12.

FIG. 2-6-12
ONE WAY CHECK VALVES



IN LINE

RIGHT ANGLE

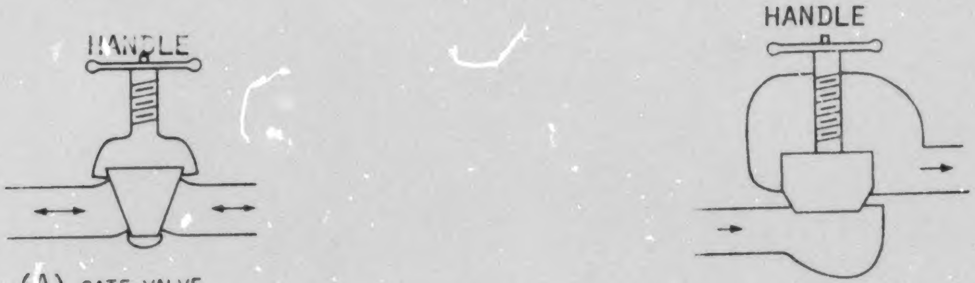
WHEN THE FLUID PRESSURE IS APPLIED TO THE INLET, IT CAUSES THE VALVE TO OPEN AGAINST THE SPRING ALLOWING FLOW TO PASS. IF THE PRESSURE IS APPLIED TO THE OUTLET SIDE OF THE CHECK VALVE, THE VALVE IS HELD FIRMLY AGAINST ITS SEAT THUS BLOCKING FLUID FLOW IN THIS DIRECTION.

B. TWO WAY VALVES.

TWO WAY VALVES, AS ON-OFF VALVES, ARE USED PRIMARILY AS SIMPLE SHUT OFF VALVES. THESE VALVES ARE OF THE SEATING ACTION DESIGN WHICH UTILIZES A GATE, DISC, BALL, OR OTHER DEVICE TO OBSTRUCT THE FLOW PATH. GENERALLY, FLUID FLOW CAN BE IN EITHER DIRECTION THROUGH THE VALVE. HOWEVER, SOME TWO WAY VALVE DESIGNS SPECIFY THE PRESSURE SIDE FROM THE DOWNSTREAM SIDE.

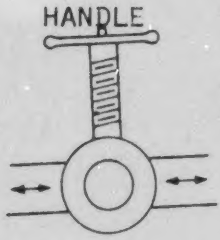
GATE VALVES, AS SHOWN IN FIGURE 2-6-13 (A), ARE GENERALLY RESTRICTED TO LOW PRESSURE APPLICATIONS, WHEREAS GLOBE- AND BALL-TYPE VALVES ARE USED FOR HIGH PRESSURE, AS FIG. 2-6-13 (B).

FIG. 2-6-13
TWO WAY VALVES



(A) GATE VALVE

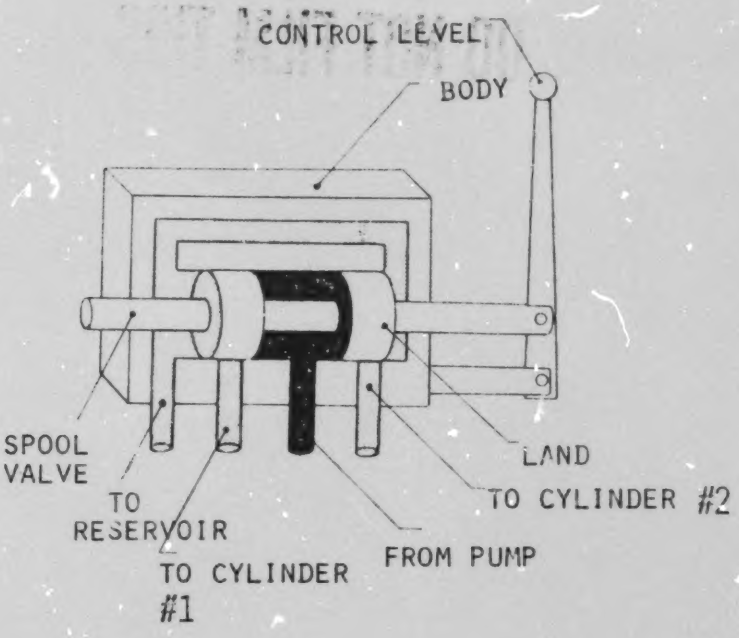
(B) GLOBE VALVE



(C) BALL VALVE

TWO WAY VALVES MAY ALSO BE OF THE SPOOL OR POPPET DESIGN AND ARE AVAILABLE AS NORMALLY OPENED OR AS NORMALLY CLOSED VALVES. IT GETS ITS NAME FROM THE FACT THAT THE VALVING ELEMENTS LOOK LIKE SPOOLS, AS SHOWN IN FIGURE 2-6-14.

FIG. 2-6-14
SPOOL DIRECTIONAL VALVE

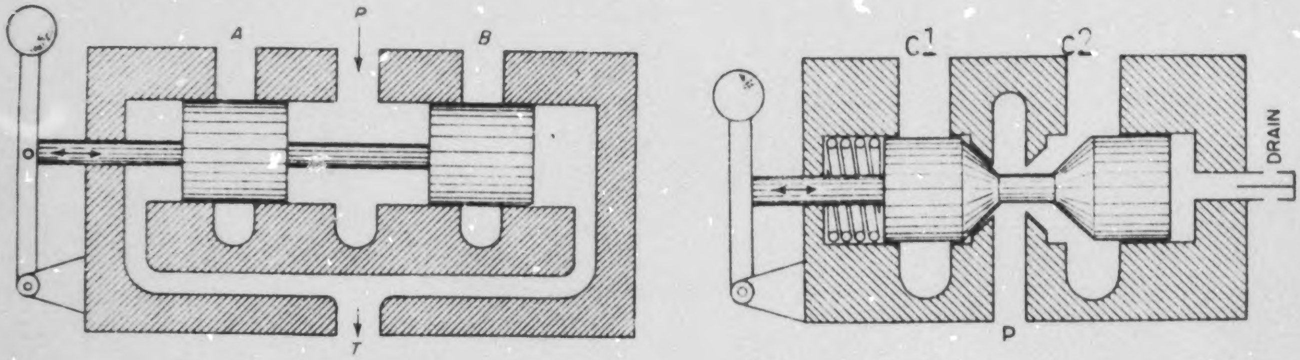


C. THREE WAY VALVES.

A DIRECTIONAL CONTROL VALVE WHOSE PRIMARY FUNCTION IS ALTERNATELY TO PRESSURIZE AND EXHAUST ONE WORKING PORT IS CALLED A THREE WAY VALVE. GENERALLY, THESE VALVES ARE USED TO OPERATE CYLINDERS OR FLUID MOTORS WHICH NEED POWER ONLY IN ONE DIRECTION, AS SHOWN IN FIGURE 2-6-15.

THREE WAY VALVES MAY BE TWO POSITION OR THREE POSITION. THEY HAVE MOST COMMONLY ONLY TWO POSITIONS, BUT IN SOME CASES A NUETRAL POSITION MAY BE NEEDED. FIGURE 2-6-15, SHOWS THE OPERATIONS OF A SPOOL TYPE, AND A TWO POSITION THREE WAY VALVE.

FIG. 2-6-15
THREE WAY VALVE



SPOOL TYPE

POPPET TYPE

THE THREE WAY VALVE WORKING PORTS ARE INLET FROM THE PUMP, OUTLET TO THE CYLINDER, AND EXHAUST TO RESERVOIR. THESE PORTS ARE GENERALLY IDENTIFIED BY P = PRESSURE; C = CYLINDER; AND T OR R = TANK OR RESERVOIR. SOMETIMES THE LETTERS A OR B ARE USED TO IDENTIFY THE PARTS CONNECTED TO AN ACTUATING CYLINDER OF FLUID MOTOR.

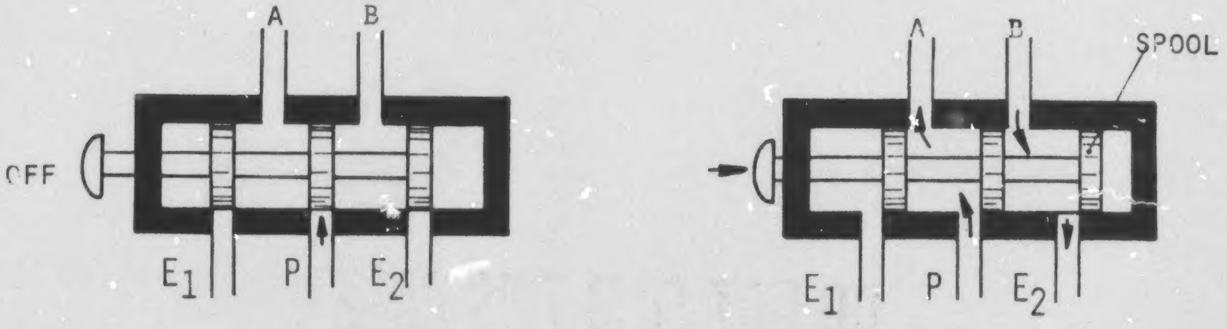
WHEN PORT IDENTIFICATION CANNOT BE READILY FOUND, BLOW LOW PRESSURE AIR THROUGH THE VARIOUS PORTS AND SHIFT THE VALVE FROM ONE POSITION TO THE OTHER TO DETERMINE PORT CONNECTION.

D. FOUR WAY VALVE.

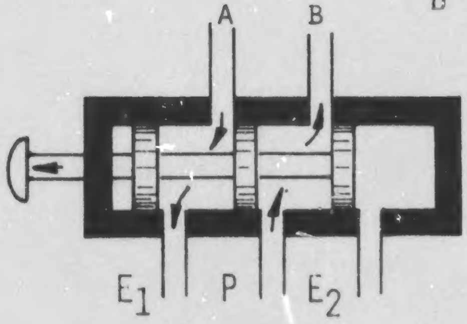
FOUR WAY VALVES, BECAUSE OF THEIR MANY DIFFERENT DESIGNS, CAN BE USED IN ALMOST ANY CONTROL APPLICATION WHERE STARTING, STOPPING OR REVERSING THE DIRECTION OF FLOW IS REQUIRED.

FOUR WAY VALVES, AS SHOWN IN FIGURE 2-6-16, ARE USED TO CONTROL THE FORWARD AND REVERSE ACTION OF DOUBLE-ACTING CYLINDERS AND ALSO TO REVERSE ROTATION OF A HYDRAULIC MOTOR. ACTUATION AND THE MARKING OF VALVE PORTS, ARE BASICALLY THE SAME AS THE TWO AND THREE WAY VALVES PREVIOUSLY DISCUSSED.

FIG. 2-6-16
FOUR WAY VALVES



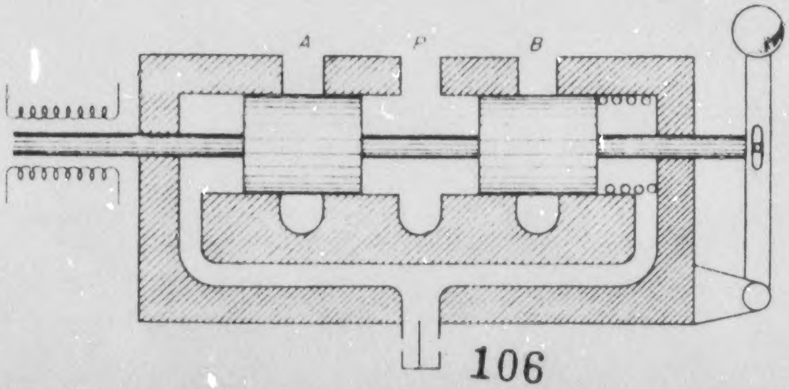
P TO A FLOW
B TO E_2 EXHAUST



A TO EXHAUST E_1
P TO B FLOW

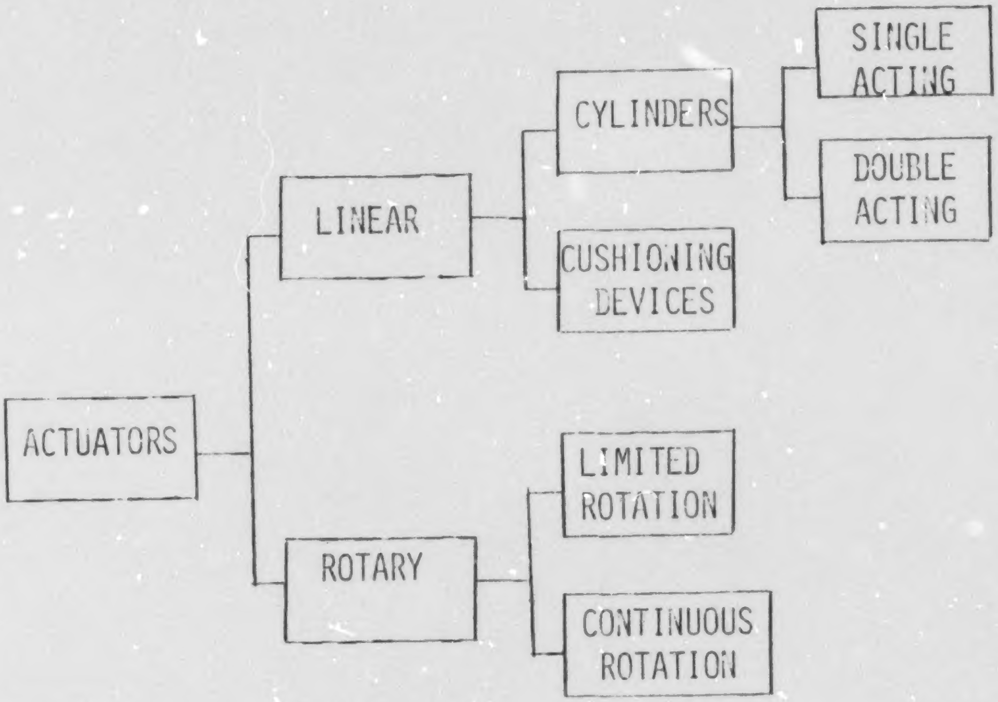
WHEN FAST ACTUATION IS NEEDED, ELECTRICAL SOLENOIDS, PILOT FLUID, AND OR MECHANICAL SPRINGS ARE USED TO SHIFT THE FOUR WAY VALVE FROM ONE POSITION TO THE OTHER. AS SHOWN IN FIGURE 2-6-17, IT IS A FOUR WAY VALVE WITH A SOLENOID AND MECHANICAL SPRING PLUS A MANUAL OVERRIDE.

FIG. 2-6-17



ACTUATORS - CYLINDER

AS WE DISCUSSED BEFORE, WE CREATED HYDRAULIC PRESSURE BY USING A PUMP, REGULATED THIS PRESSURE BY USING A PRESSURE CONTROL VALVE; CONTROLLED THE AMOUNT OF FLOW WITH A FLOW CONTROL VALVE; AND EVEN USED A DIRECTIONAL CONTROL VALVE TO DIRECT THE FLOW WHERE WE WANTED THEM TO GO. NOW WE ARE GOING TO TALK ABOUT HOW TO CHANGE THIS CONTROLLED HYDRAULIC POWER TO BE A USEFUL MECHANICAL POWER. THIS IS ACCOMPLISHED BY HYDRAULIC ACTUATORS--CYLINDERS AND MOTORS. GENERALLY, THE HYDRAULIC ACTUATOR CAN BE CLASSIFIED INTO SEVERAL CATEGORIES AS FOLLOWS:


ACTUATORS
LINEAR
ROTARY
CYLINDERS
CUSHIONING DEVICES
SINGLE ACTING
DOUBLE ACTING
LIMITED ROTATION
CONTINUOUS ROTATION

1. CYLINDERS

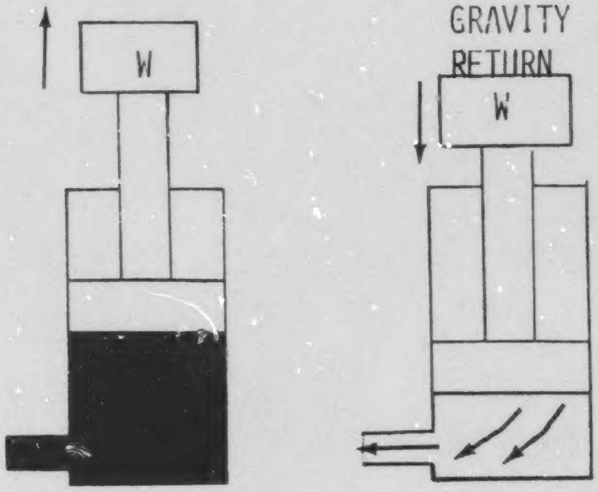
A HYDRAULIC CYLINDER IS A DEVICE WHICH CONVERTS FLUID POWER INTO LINEAR MECHANICAL FORCE AND MOTION. IT USUALLY CONSISTS OF A MOVABLE ELEMENT, SUCH AS A PISTON AND PISTON ROD, PLUNGER OR RAM, OPERATING WITHIN A CYLINDER BORE.

THERE ARE TWO TYPES OF CYLINDERS SINGLE ACTING AND DOUBLE ACTING CYLINDERS.

A. SINGLE ACTING CYLINDER.

THE SINGLE ACTING CYLINDER IS THAT IN WHICH THE FLUID ENTERS TO OR EXHAUSTS BACK FROM THE CYLINDER IN THE SAME PORT, AS SHOWN IN FIGURE 2-6-17. WHEN THE HYDRAULIC FLUID UNDER PRESSURE IS ALLOWED TO ENTER THE CYLINDER AND WHEN THE PRESSURE IS RELEASED, THE FLUID MOVES BACK AND THE PISTON RETURNS TO THE BOTTOM OF THE CYLINDER BY GRAVITY OR SPRING.

FIG. 2-6-17
SINGLE ACTING CYLINDER

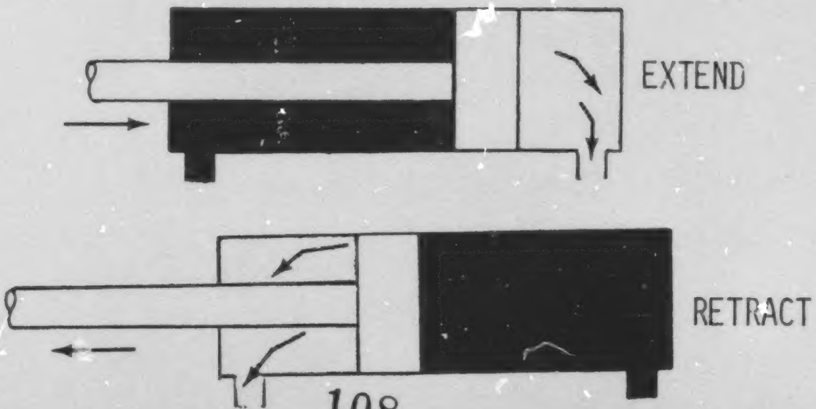


RAISE

LOWER

B. DOUBLE ACTING CYLINDER.

FIGURE 2-6-18, DEPICTS A DOUBLE ACTING HYDRAULIC CYLINDER. THE FLUID FLOWS INTO ONE SIDE TO EXTEND THE PISTON AND THE PISTON IS RETRACTED WHEN THE FLUID FLOWS INTO THE OTHER SIDE OF THE CYLINDER.



2. THE FORCE OUTPUT OF A HYDRAULIC CYLINDER.
   A. SINGLE ACTING CYLINDER.

FORCE = PRESSURE x PISTON AREA

$$F = P \times A$$

(EXAMPLE): #1

CALCULATING FORCE WHEN P AND A ARE KNOWN. IF P = 2000 POUNDS PER SQUARE (PSI) D = 3.2 INCHES $\left(A = \frac{\pi D^2}{4}\right)$

SOLUTION:

$$A = \frac{\pi D^2}{4} = \frac{3.14 \times (3.2)^2}{4} = 8.04 \ (IN^2)$$

$$F = PA = 2000 \times 8.04 = 16080 \ (LBS)$$

(EXAMPLE): #2

COMPUTE THE SIZE OF THE CYLINDER PISTON OPERATING FROM A SYSTEM, $P = 1600 \ LBF/IN^2$, TO MOVE A LOAD RESISTANCE OF 80000 LBF.

SOLUTION:

$$D = \sqrt{\frac{4F}{\pi P}} = \sqrt{\frac{4 \times 80000}{3.14 \times 1600}} \doteq 8 \ IN$$

B. DOUBLE ACTING CYLINDER.

FORCE = (PISTON AREA x PISTON PRESSURE) - (ROD SIDE AREA x ROD SIDE PRESSURE)

(EXAMPLE):

PISTON DIAMETER =   INCHES.
ROD DIAMETER = 1.8 INCHES.
PISTON PRESSURE = 1500 PSI.
ROD SIDE PRESSURE = 500 PSI.
F = ?

SOLUTION: $\text{PISTON AREA} = \frac{\pi D}{4} = \frac{3.14 \times (4)^2}{4} = 12.6\ (\text{IN}^2)$

$$\text{ROD AREA} = \frac{3.14 \times (1.8)^2}{4} = 2.55\ (\text{M}^2)$$

$$F = (1500 \times 12.6) - \left[500 \times (12.6 - 2.55)\right]$$
$$= 18900 - 2025 = 13875 \text{ LB}$$

3. VELOCITY OF A CYLINDER

THE VELOCITY OF A CYLINDER AS IT EXTENDS OR RETRACTS DEPENDS UPON HOW FAST THE FLUID IS FED INTO THE CYLINDER AND THE AREA OF THE CYLINDER. VELOCITY VARIES DIRECTLY WITH THE GAL/MIN (GPM). VELOCITY VARIES INVERSELY WITH THE AREA. MATHEMATICALLY, THIS MAY BE EXPRESSED AS:

$$V = \frac{GPM}{A}, \quad V(FT/MIN) = \frac{GPM}{IN^2}$$

CORRECT UNITS ON BOTH SIDES.

$$V(FT/MIN) = \frac{GAL/MIN \times 231\ IN^3/GAL \times \frac{1\ FT}{12\ IN}}{IN^2}$$

$$= \frac{GAL/MIN}{IN^2} \times \frac{231\ IN^2\ FT}{12\ GAL}$$

$$= \frac{GPM}{A} \times 19.25$$

THE FACTOR 19.25 IN^2 FT/GAL IS A CONSTANT WHICH CAN BE USED FOR FINDING THE VELOCITY OF ANY CYLINDER IN FEET PER MINUTE.

A. SINGLE ACTING CYLINDER.

$$V = \frac{Q \times 19.25}{A}$$

WHERE V= ROD VELOCITY (FT/MIN)
Q= FLOW RATE (GAL/MIN)
A= IN^2

(EXAMPLE):

FLOW RATE INTO CYLINDER = Q = 5 GPM
PISTON DIMETER = D = 3 IN
THEN V = ?

SOLUTION:

$$A = \frac{\pi D^2}{4} = \frac{3.14 \times (3)^2}{4} = 7.07\ (IN^2)$$

$$V = \frac{5 \times 19.25}{7.07} = 13.6\ (FT/MIN)$$

B. DOUBLE ACTING CYLINDER.

(EXAMPLE):

PISTON DIAMETER $D = 4$ IN
ROD DIAMETER $d = 2$ IN
PISTON AREA $A_P = 12.6\ IN^2$
ROD AREA $A_R = 3.14\ IN^2$

(1) IF THE CYLINDER IS EXTENDING AND THE FLOW INTO THE PISTON SIDE IS 10 GPM, THEN:

$$V = \frac{10 \times 10.25}{12.6} = 15.3\ FT/MIN$$

(2) IF THE CYLINDER IS RETRACTING AND THE FLOW INTO THE ROD SIDE IS 10 GPM, THEN:

$$V = \frac{10 \times 10.25}{9.42} = 20.4\ FT/MIN$$

4. OUTPUT POWER OF A CYLINDER.

EQUATION: $$W = \frac{V \times F}{33{,}000}$$

WHERE, W = POWER OUT (HORSEPOWER)
V = ROD VELOCITY (FT/SEC)
F = ROD FORCE (POUNDS)

(EXAMPLE):
V = 10 FT/SEC
F = 15000 POUNDS

SOLUTION: $$W = \frac{(10)\ (15000)}{33000} = 4.54\ (\text{HP})$$

5. THE FLOW RATE REQUIRED TO MOVE A CYLINDER A GIVEN DISTANCE IN A GIVEN TIME.

EQUATION: $$Q = \frac{A \times L}{T \times 231}$$

WHERE, Q = FLOW RATE IN GALLONS PER MINUTE (GPM)
A = AREA IN SQUARE INCHES (IN^2)
L = LENGTH IN INCHES (IN)
T = TIME IN MINUTES (MIN)

(EXAMPLE):
TO MOVE A 2 INCH DIAMETER CYLINDER 20 INCHES IN 0.5 MINUTES, THEN THE FLOW RATE Q = ?.

SOLUTION:

$$A = \frac{\pi D^2}{4} = \frac{3.14 \times (2)^2}{4} = 3.14\ (IN^2)$$

$$Q = \frac{(3.14) \times 20}{0.5 \times 231} = 0.54\ (\text{GPM})$$

ACTUATOR - MOTOR

A HYDRAULIC MOTOR IS A DEVICE WHICH CONVERTS FLUID ENERGY INTO MECHANICAL FORCE AND MOTION. IT USUALLY PROVIDES ROTARY MECHANICAL MOTION.

HYDRAULIC MOTORS AND HYDRAULIC PUMPS LOOK ALIKE IN MANY RESPECTS, BUT THE MOTORS WORK IN A MANNER JUST OPPOSITE TO THE WAY IN WHICH THE PUMPS WORK. THEY USE THE FLUID DELIVERED BY THE PUMP TO PROVIDE A ROTATING FORCE AND MOTION.

THERE ARE TWO GENERAL CATEGORIES OF HYDRAULIC MOTORS, FIXED DISPLACEMENT AND VARIABLE DISPLACEMENT. IN THE FIXED DISPLACEMENT CATEGORY, GEAR, VANE AND PISTON DESIGNS ARE USED IN THE VARIABLE IN DISPLACEMENT CATEGORY, PISTON DESIGNS ARE USED.

1. TYPES OF HYDRAULIC MOTORS.

   A. GEAR TYPE HYDRAULIC MOTOR.

   GEAR TYPE HYDRAULIC MOTORS ARE OFTEN USED AS EITHER PUMPS OR MOTORS. HOWEVER, SINCE HYDRAULIC MOTORS ARE SUPPLIED WITH FLUID FROM THE PUMP AND ARE UNDER PRESSURE WHILE DOING WORK, BEARINGS, TYPE OF SEALS, AND DRAINS ARE SOMETIMES AFFECTED.

   THERE ARE TWO TYPES OF HYDRAULIC GEAR TYPE MOTORS: INTERNAL OR EXTERNAL GEAR MOTORS, AS SHOWN IN FIGURE 2-6-18. THE EXTERNAL GEAR DESIGN IS ECONOMICAL AND AVAILABLE AS SINGLE OR TANDAM UNITS. A SET OF MATCHED GEARS IF FITTED INTO A CLOSELY MACHINED HOUSING, THE GEARS ROTATE TOGETHER AS FLUID ENTERS THE SPACE BETWEEN THE MAJOR AND MINOR DIAMETERS. AS THE MOTOR RUNS, SMALL VOLUMES OF FLUID ARE TRAPPED BETWEEN THE GEAR TEETH AND ARE CARRIED TO THE OUTLET. THE FLUID AT THE OUTLET IS EXPELLED AT A LOW PRESSURE.

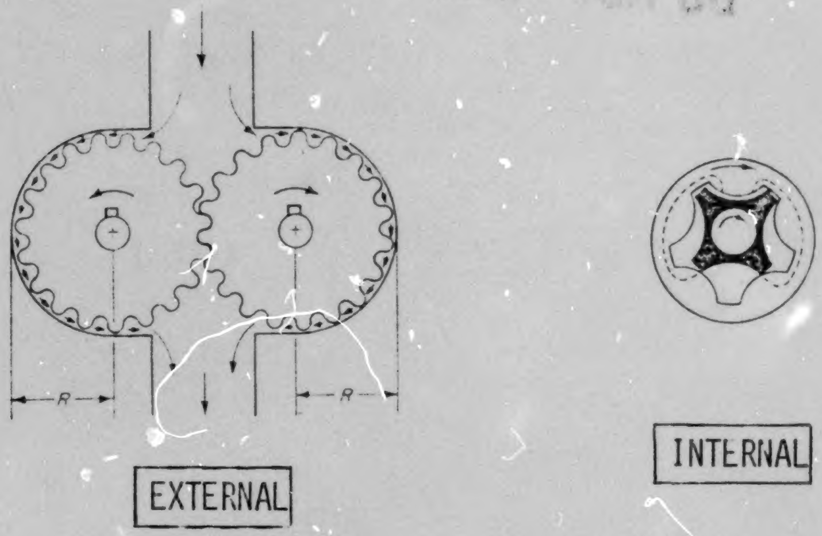
   B. VANE TYPE HYDRAULIC MOTORS.

   VANE TYPE HYDRAULIC MOTORS ARE OF THE SAME GENERAL DESIGN AS VANE PUMPS EXCEPT THAT THE VANES MUST BE HELD TIGHTLY AGAINST THE CONTOUR OF THE RETAINING RING TO PROVIDE TORQUE. SEALS, BEARINGS AND DRAINS ARE IMPORTANT CONDIDERATIONS, AS THEY ARE WITH ALL OTHER DESIGNS OF FLUID MOTORS. FLUID FORCED INTO THE VANE MOTOR FROM THE PUMP PUSHES AGAINST

THE VANES AND CAUSES THE ROTOR AND SHAFT ASSEMBLY TO RUN. AS THE ROTOR TURNS A SMALL VOLUME OF FLUID IS TRAPPED AND CARRIED TO THE OUTLET AND EXPELLED AT A LOW PRESSURE. SOME VANE MOTORS ARE DESIGNED TO BALANCE THE LOAD ON THE SHAFT BEARING BY HAVING TWO INLET AND TWO OUTLET PORTS. THE INLET PORTS ARE POSITIONED DIRECTLY OPPOSITE EACH OTHER.

FIG. 2-6-18

GEAR MOTOR - INTERNAL AND EXTERNAL



EXTERNAL

INTERNAL

C. PISTON TYPE HYDRAULIC MOTORS.

THERE ARE TWO TYPES OF PISTON DESIGNS FOR HYDRAULIC MOTORS: THE AXIAL PISTON UNITS AND RADIAL PISTON TYPE MOTORS. BOTH DESIGNS CAN BE EITHER FIXED OR VARIABLE MOTORS. THEIR CONSTRUCTION FEATURES ARE NEARLY THE SAME AS THE PUMP UNITS.

THE AXIAL PISTON MOTORS USE THE VALVE PLATE METHOD OF DISPLACING FLUID, AND THE RADIAL DESIGN USE THE PINTLE ARRANGEMENT OF PORTING.

IN OPERATION, EACH PISTON IS FORCED TO MOVE, IT ROTATES FROM THE INLET TO THE OUTLET. WHEN DOING THIS, IT CARRIES A SMALL AMOUNT OF FLUID FROM THE INLET TO THE OUTLET. THIS FLUID IS EXPELLED FROM THE OUTLET AT A LOWER PRESSURE.

2. CALCULATION OF HYDRAULIC MOTORS.

A. MOTOR LOAD TORQUE.

TORQUE = DISTANCE x FORCE.

WHERE:

TORQUE = FT-POUNDS OR INCH-POUNDS.

DISTANCE = INCHES OR FEET. (DISTANCE FROM CENTER OF SHAFT TO LINE OF ACTION OF APPLIED FORCE)

FORCE = POUNDS.

(EXAMPLE):

IF A 100 POUND FORCE IS APPLIED TO THE SHAFT OF A HYDRAULIC MOTOR ONE FOOT FROM THE CENTER OF THE SHAFT, WHAT WILL ITS OUTPUT TORQUE BE?

TORQUE = DISTANCE x FORCE

= 1 x 100 = 100 (FT-POUND)

B. DISPLACEMENT OF A HYDRAULIC MOTOR.

$$D = \frac{231Q}{N}$$

WHERE:

D = DISPLACEMENT IN IN^3/REV

Q = MOTOR INLET FLOW RATE IN GPM

N = SHAFT SPEED IN RPM

(EXAMPLE):

WHAT IS THE DISPLACEMENT OF A MOTOR WHICH HAS A SHAFT SPEED OF 1800 RPM AND INLET FLOW RATE OF 20 GPM.

$$D = \frac{231 \times Q}{N} = \frac{231 \times 20}{1800} = 2.56 \ (M^3/REV)$$

C. SPEED OF A HYDRAULIC MOTOR.

$$N = \frac{231\ Q}{D}$$

(EXAMPLE):

WHAT IS THE SPEED OF A MOTOR WITH 2.56 IN^3/REV OF DISPLACEMENT AND AN INLET FLOW RATE OF 25 GPM?

$$N = \frac{231\ Q}{D} = \frac{231 \times 25}{2.56} = 2255\ (RPM)$$

D. PRESSURE OF A HYDRAULIC MOTOR.

$$P = \frac{TORQUE \times 2\pi}{D}$$

WHERE:

P = INLET PRESSURE IN POUNDS PER SQUARE INCH (PSI)
TORQUE = IN-LBS
D = DISPLACEMENT IN IN^3/REV

(EXAMPLE):

A MOTOR HAS A TORQUE = 700 IN-LBS, AND A D = 2.56 CUBIC INCHES PER REVOLUTION. WHAT IS THE INLET PRESSURE OF IT?

$$P = \frac{TORQUE \times 2\pi}{D} = \frac{700 \times 6.28}{2.56} = 1700\ (PSI)$$

E. MOTOR POWER.

$$\text{POWER}_{IN} = \frac{P \times Q}{1714} \text{ - - - ①}$$

$$\text{POWER}_{OUT} = \frac{N \times \text{TORQUE}}{5252} \text{ - - - ②}$$

WHERE:

POWER = HORSEPOWER (HP)
Q = INLET FLOW RATE IN GPM
N = SHAFT SPEED IN RPM
TORQUE = OUTPUT TORQUE IN FT-LBS

(EXAMPLE): #1

WHAT IS THE INPUT POWER OF A HYDRAULIC MOTOR WHICH HAS 20 GPM INLET FLOW RATE AND 3000 PSI INLET PRESSURE?

$$\text{POWER}_{IN} = \frac{P \times Q}{1714} = \frac{3000 \times 20}{1714} = 35 \text{ (HP)}$$

(EXAMPLE): #2

IF N = 2400 RPM, TORQUE = 70 FT-LBS, WHAT IS THE OUTPUT POWER OF IT?

$$\text{POWER}_{OUT} = \frac{N \times \text{TORQUE}}{5252} = \frac{2400 \times 70}{5252} = 32 \text{ (HP)}$$

LESSON PLAN #1

HYDRAULIC POWER SYSTEM

ASSIGNMENT SHEET 1

AFTER READING THE INFORMATION SHEET (IS2-1-1, THROUGH IS2-1-6) PROVIDED, COMPLETE THE FOLLOWING QUESTIONS IN WRITING OR AS REQUESTED BY YOUR INSTRUCTOR.

1. DESCRIBE THE FUNCTIONS OF A RESERVOIR.

2. MATCH THE TERM ON THE RIGHT WITH THE CORRECT DEFINITION.

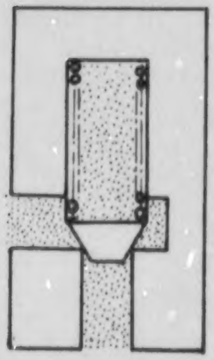
___	A.	A DEVICE WHICH CREATES THE FLOW OF FLUID.	1.	BACK PRESSURE
___	B.	PRESSURE IN THE RETURN LINE CAUSED BY FLOW THROUGH THE LINE FROM THE PUMP TO THE RESERVOIR.	2.	VOLUMETRIC EFFICIENCY
___	C.	THE ACTUAL FLOW RATE FROM A PUMP DIVIDED BY THE THEORETICAL FLOW RATE.	3.	PUMP
___	D.	THE VOLUME OF FLUID WHICH IS TRANSFERRED FROM THE PUMP INLET TO THE OUTLET DURING ONE REVOLUTION OF THE PUMP.	4.	DISPLACEMENT

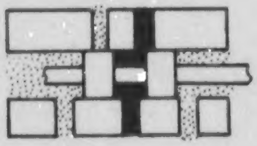
3. CALCULATE THE PUMP DISPLACEMENT FOR A PUMP WHICH HAS AN OUTLET OF 30 GPM AT 200 RPM.

4. CALCULATE THE OUTPUT POWER FOR A PUMP OPERATING WITH 18 GPM FLOW AND 2700 PSI OUTLET PRESSURE.

5. LIST FOUR COMMON CAUSES OF HYDRAULIC PUMP FAILURE.

6. IDENTIFY THE TYPES OF DIRECTIONAL CONTROL VALVES.





7. MATCH THE TERM ON THE RIGHT WITH THE CORRECT DEFINITION.

___ A. OIL FLOWS INTO ONLY ONE SIDE OF THE CYLINDER.

___ B. PRESSURE IN THE RETURN LINES CAUSED BY FLOW IN THESE LINES.

___ C. EFFECTIVE AREA ON THE ROD SIDE OF THE CYLINDER; EQUAL TO THE PISTON AREA MINUS THE ROD AREA.

___ D. AN ACTUATOR WHICH CONVERTS HYDRAULIC POWER INTO LINEAR MECHANICAL FORCE AND MOTION.

1. $\frac{\pi(D-d)^2}{4}$
2. BACK PRESSURE
3. CYLINDER
4. SINGLE-ACTING CYLINDER

8. USING THE FORMULA FOR THE FLOW RATE REQUIRED TO MOVE A CYLINDER A GIVEN DISTANCE IN A GIVEN TIME, $Q=\frac{A \times L}{T \times 231}$, CALCULATE THE FLOW RATE REQUIRED TO MOVE A 2 INCH DIAMETER CYLINDER 10 INCHES IN ONE MINUTE.

SYLLABUS SHEET FOR LESSON 2
ROBOT SERVICE AND REPAIR

UNIT #2 POWER SUPPLY

ACCESSORIES OF HYDRAULIC SYSTEMS

LESSON OBJECTIVE--UPON COMPLETION OF THIS LESSON, THE STUDENT SHOULD BE ABLE TO:

1. VERBALLY CLASSIFY THE TYPES OF FILTERS, LINES, FITTINGS AND SEALS USED ON A HYDRAULIC POWER SYSTEM.
2. VERBALLY DESCRIBE THE FUNCTIONS OF THOSE ACCESSORIES.

TEACHING AIDS:

1. T2-2-1 TYPES OF FILTERS
2. T2-2-2 THE LOCATION OF A FILTER
3. T2-2-3 THE SIZE OF A STEEL PIPE
4. T2-2-4 HOSE TYPES AND HOSE CONSTRUCTION
5. T2-2-5 METHODS OF TUBING
6. T2-2-6 METHODS OF TUBING (CONTINUED)
7. T2-2-7 TYPES OF FITTINGS USED IN TUBING
8. T2-2-8 TYPES OF HOSE ENDS

INFORMATIONAL ASSIGNMENTS:

1. IS2-2-1 SUMMARY OF HYDRAULIC SYSTEM ACCESSORIES
ANSWER QUESTIONS FOUND ON ASSIGNMENT SHEETS
1. As2-2-1 ACCESSORIES OF HYDRAULIC SYSTEMS

REFERENCES:

PEASE, D.A., BASIC FLUID POWER, PRENTICE-HALL, INC. N.J., 1967.
OSTER, JON, BASIC APPLIED FLUID POWER; HYDRAULICS, McGRAW-HILL BOOK COMPANY, N.Y., 1969.

STEP 1-INTRODUCTION FOR PREPARATION OF THE STUDENT:

[illegible] PARTS IN A HYDRAULIC SYSTEM, SUCH AS FILTERS, LINES, FITTINGS, AND SEALS, ETC., ARE VERY IMPORTANT TO THE REAL ROBOTIC APPLICATIONS. IF ANY OF THESE COMPONENTS GET DEFECTED OR IMPROPERLY USED THEY WILL CAUSE A PROBLEM IN THE SYSTEM. IN THIS UNIT, THE STUDENT WILL LEARN THE FUNCTIONS AND KNOW THE CLASSIFICATIONS OF THE FILTERS, LINES, FITTINGS AND SEALS, ETC., THAT ARE USED IN A HYDRAULIC SYSTEM, FROM WHICH THE STUDENT WILL BE ABLE TO SELECT, USE AND DETECT THE PARTS FOR HYDRAULIC POWER SYSTEM APPLICATIONS.

LESSON SUMMARY AND REVIEW:

1. WHAT ARE THE FUNCTIONS OF FILTERS?

2. LIST THREE CONSIDERATIONS IN THE SELECTION OF LINES FOR A HYDRAULIC SYSTEM.

3. LIST THREE FACTORS TO CONSIDER WHEN ROUTING TUBING IN A HYDRAULIC SYSTEM.

4. WHAT IS THE FLARED END OF THE TUBING USED FOR?

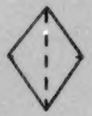
5. WHAT IS THE GENERAL FUNCTION OF A SEAL USED FOR?

SUMMARY OF HYDRAULIC SYSTEM ACCESSORIES

I. FILTER
  A. TYPES OF FILTERS (AS TRANSPARENCY T2-2-1). THERE ARE TWO TYPES OF FILTERS IN HYDRAULIC SYSTEMS.
    1. SURFACE FILTER
      A. A SURFACE FILTER HAS A SINGLE SURFACE THAT CATCHES AND REMOVES DIRT PARTICLES LARGER THAN THE HOLES IN THE FILTER.
    2. DEPTH FILTER
      A. A DEPTH FILTER USES A LARGE VOLUME OF FILTER MATERIAL TO TRAP THE PARTICLES AS THE OIL PASSES THROUGH.
  B. THE FUNCTIONS OF FILTERS
    1. TO REMOVE DIRT THAT HAS ENTERED THE SYSTEM THROUGH BREATHER CAPS, SEALS, OPEN LINES, AND UNCLEAN COMPONENTS.
    2. TO REMOVE METAL PARTICLES GENERATED BY WEAR PROCESSES.
    3. TO REMOVE PARTICLES RESULTING FROM RUST OR CORROSION OF INTERNAL SURFACES.
  C. THE LOCATIONS OF FILTERS IN THE HYDRAULIC SYSTEM (AS TRANSPARENCY T2-2-2).
    1. SUCTION LINE FILTER
      A. A SUCTION FILTER IS LOCATED AT THE INLET OF THE PUMP. A SUCTION LINE FILTER IS USED ONLY TO PREVENT OBJECTS SUCH AS NUTS, BOLTS, AND METAL CHIPS FROM ENTERING THE PUMP.
    2. PRESSURE LINE FILTER
      A. A PRESSURE LINE FILTER IS LOCATED AT THE OUTLET OF THE PUMP.
    3. RETURN LINE FILTER
      A. A RETURN LINE FILTER IS LOCATED BETWEEN THE OUTLET OF THE LOAD AND THE RESERVOIR.
  D. THE INFORMATION OF SELECTING THE PROPER FILTER FOR ANY APPLICATION.
    1. THE SIZE AND PHYSICAL NATURE OF THE DETRIMENTAL CONTAMINANTS TO BE REMOVED.
    2. THE VISCOSITY, DENSITY, OPERATING TEMPERATURES AND CORROSIVE PROPERTIES OF THE HYDRAULIC FLUID BEING USED.

    3. THE MATERIALS USED FOR FABRICATING THE SYSTEM BEFORE THE FILTER AND AFTER THE FILTER. SEALS, FITTINGS, TUBING, HOSE, AND OTHER PARTS SHOULD BE ANALYZED.
    4. THE OPERATING CHARACTERISTICS OF THE SYSTEM, SUCH AS SHOCK LOAD, FLUID VELOCITY, AND DIRECTION.
    5. PRESSURES AND PRESSURE DROPS THAT THE FILTER MEDIA MUST ENCOUNTER DURING THE SYSTEM'S OPERATION.
    6. THE COMPONENT IN THE SYSTEM THAT REQUIRES THE CLOSEST TOLERANCES, AND HENCE, THE LEAST CONTAMINATION.

E. SYMBOL FOR A FILTER



F. METHODS FOR ASSURING HYDRAULIC SYSTEM CLEANLINESS.
    1. CHANGE FLUID AND FILTER REGULARLY
    2. FILL SYSTEM ONLY WITH CLEAN OIL
    3. CLEAN DIRT OFF BREATHER CAPS AND FILTER PLUGS PRIOR TO OPENING SYSTEM
    4. USE A CLEAN, LINT-FREE TOWEL TO WIPE DIPSTICK
    5. REPLACE WORN SEALS
    6. KEEP WORK AREA CLEAN
    7. CLEAN AND FLUSH COMPONENTS PRIOR TO INSTALLING SYSTEM

II. LINES

A. THE CONSIDERATIONS FOR SELECTING LINES FOR A HYDRAULIC SYSTEM
    1. THE TYPE OF MATERIALS: STEEL, IRON, PLASTIC
    2. CAPACITY
    3. PRESSURE RATING

B. TYPES OF LINES
    1. STEEL PIPE
        A. SIZE: THE SIZE OF STEEL PIPE ARE SPECIFIED BY NOMINAL INSIDE DIAMETER. THE WALL THICKNESS, HOWEVER, IS DESCRIBED BY A SCHEDULE NUMBER (AS SHOWN IN TRANSPARENCY T2-2-3).
        B. PRESSURE RANGE: THERE ARE THREE PRESSURE RANGES OF STEEL PIPE LINES WHICH ARE VERY HIGH PRESSURE LINES (SCHEDULE 160), HIGH PRESSURE LINES (SCHEDULE 80), AND LOW PRESSURE LINES (SCHEDULE 40).

2. STEEL TUBING

A. SIZE: THE TABLE BELOW SHOWS THE SIZE CLASSIFICATION OF TUBES.

TUBE (O.D)	WALL THICKNESS	TUBE (I.D)	PRESSURE RANGE
1/8	0.028	0.069	LOW
	0.032	0.061	HIGH
	0.035	0.055	VERY HIGH
3/16	0.032	0.1235	LOW
	0.035	0.1175	HIGH

B. MATERIAL AND CONSTRUCTION: THE TABLE BELOW SHOWS THE CLASSIFIED STEEL TUBES BY MATERIAL AND CONSTRUCTION.

MATERIAL	CONSTRUCTION
-STAINLESS	-SEAMLESS
-NON-STAINLESS	-WELDED

3. HYDRAULIC HOSE: THE TABLE OF TYPES AND CONSTRUCTION OF THE HOSE AS SHOWN IN TRANSPARENCY T2-2-4 IS STANDARDLY DEVELOPED BY THE SOCIETY OF AUTOMOTIVE ENGINEERS.

C. FACTORS TO CONSIDER WHEN ROUTING TUBING IN A HYDRAULIC SYSTEM (AS SHOWN IN TRANSPARENCIES T2-2-5 AND T2-2-6).

1. AVOID STRAIGHT-LINE HOOK-UPS.
2. USE THE FEWEST AND SIMPLEST BENDS POSSIBLE.
3. SUPPORT LONG RUNS OF TUBING.
4. AVOID INTERFERENCE WITH OPERATOR CONTROLS.

III. FITTINGS

A. TYPES OF FITTINGS USED WITH TUBING
(THERE ARE THREE TYPES OF FITTINGS USED ON THE END OF THE TUBING, AS SHOWN IN TRANSPARENCY T2-2-7.)

1. FLARE. THE END OF THE TUBING FLARED TO MATE WITH A FITTING 37° IS MOST COMMON AND 45° IS USED IN SOME LOW PRESSURE APPLICATION.
2. FLARELESS. THE TUBING MATERIAL IS COMPRESSED TO FORM A BUILD-UP OF TUBING MATERIAL AROUND A RATING RING. THIS RING IS USED TO HOLD THE FITTING ON THE TUBING.
3. BRAZE-ON. THE FITTING IS BRAZED OR WELDED ONTO THE END OF THE TUBING.

B. TYPES OF HOSE-ENDS (AS SHOWN IN TRANSPARENCY T2-2-8).

1. PERMANENT. THE FITTING IS CRIMPED OR SWAGED ONTO THE HOSE.
2. REUSABLE. THERE ARE THREE CATEGORIES OF THIS TYPE.
    A. NONSKIVE. THE HOSE COVER IS NOT REMOVED THE HOSE-END NIPPLE IS INSERTED INTO THE HOSE. A SOCKET (SLEEVE) IS SCREWED OR PUSHED ONTO THE HOSE-END TO CLAMP IT TO THE HOSE.
3. SKIVE. THE HOSE COVER IS REMOVED PRIOR TO THE INSTALLATION OF THE HOSE-END. THE INSTALLATION IS THE SAME AS THE NONSKIVE.
4. CLAMP-ON. A BARDED HOSED-END NIPPLE IS INSERTED INTO THE HOSE AND A CLAMP IS BOLTED ONTO THE HOSE TO PROVIDE GRIP.

IV. SEALS. THE SUCCESS OF APPLYING FLUID POWER TO ANY APPLICATION DEPENDS LARGELY ON THE ABILITY OF THE SEALING DEVICES TO PREVENT BOTH INTERNAL AND EXTERNAL LEAKAGES IN THE SYSTEM. SO THE SEALING DEVICES ARE VERY IMPORTANT FOR A HYDRAULIC POWER SYSTEM.

A. THE TYPES OF SEALING DEVICES. THERE ARE MANY KINDS OF SEALING DEVICES WHICH ARE USED FOR HYDRAULIC POWER SYSTEMS TO KEEP HYDRAULIC FLUID FROM FLOWING BETWEEN CERTAIN PASSAGES OR KEEP FOREIGN MATERIALS FROM ENTERING THE SYSTEM (AS SHOWN IN TRANSPARENCY T2-2-8, T2-2-9)

B. TYPES OF SEAL CONSTRUCTION

1. T RING SEAL: AS SHOWN IN FIG. 2-2-1

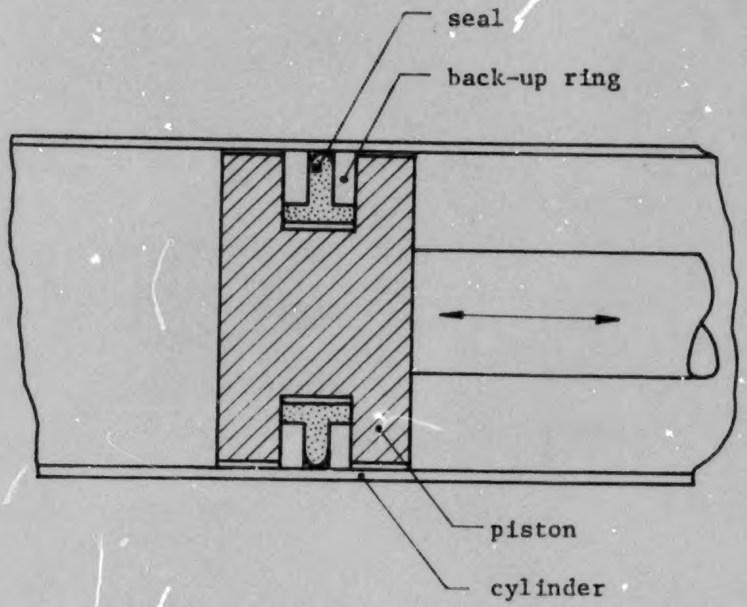

seal
back-up ring
piston
cylinder

FIG. 2-2-1 T RING SEAL

2. LIP TYPE SEAL, AS SHOWN IN FIG. 2-2-2

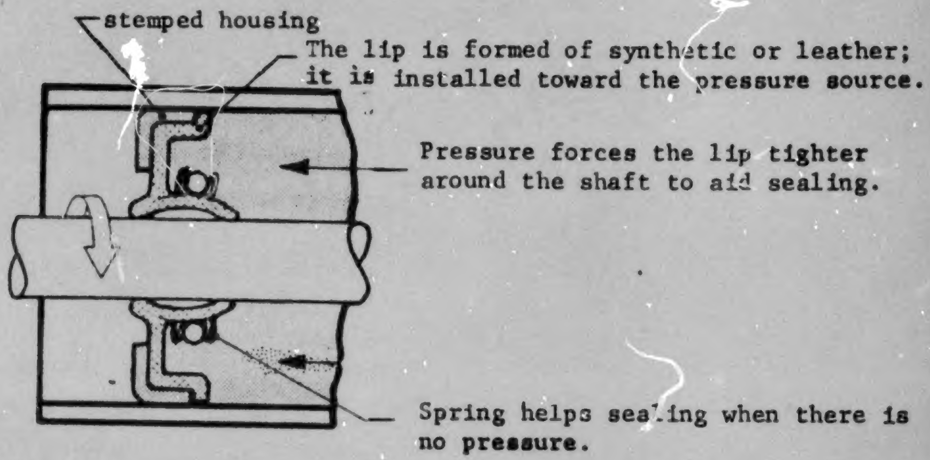

stemped housing
The lip is formed of synthetic or leather; it is installed toward the pressure source.
Pressure forces the lip tighter around the shaft to aid sealing.
Spring helps sealing when there is no pressure.

FIG. 2-2-2 LIP-TYPE SEAL

3. CAP SEAL: AS SHOWN IN FIG. 2-2-3

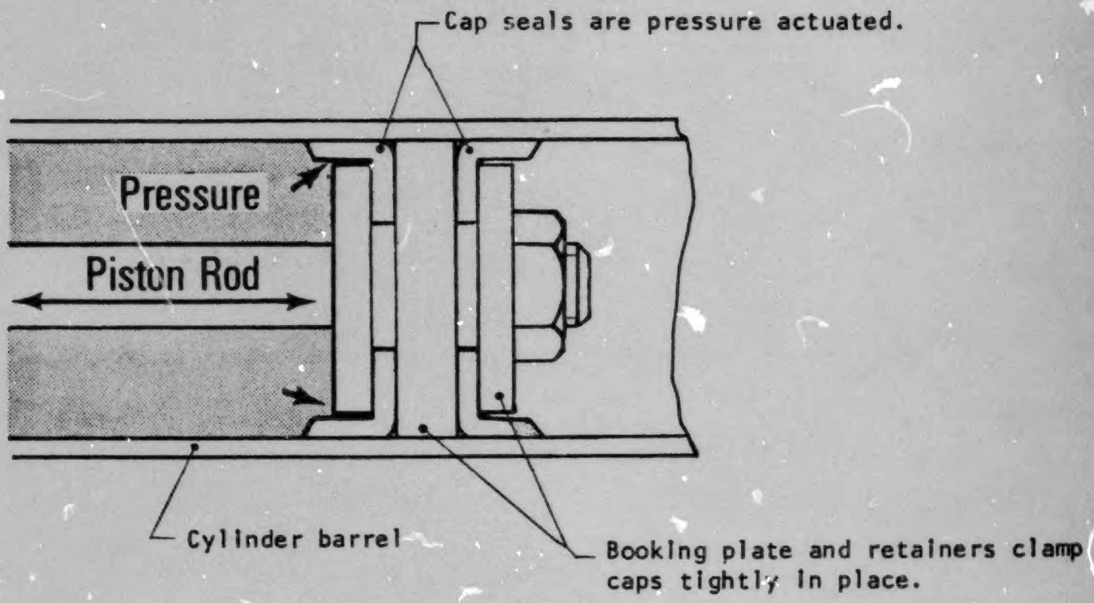

Cap seals are pressure actuated.
Pressure
Piston Rod
Cylinder barrel
Booking plate and retainers clamp caps tightly in place.

FIG. 2-2-3 CAP SEAL

4. FACE-TYPE SEAL: AS SHOWN IN FIG. 2-2-4

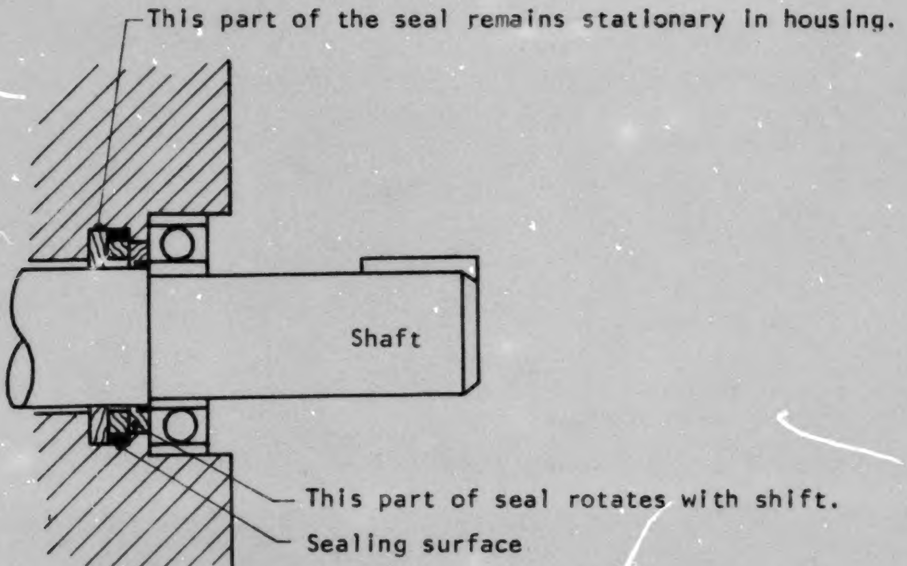

This part of the seal remains stationary in housing.
Shaft
This part of seal rotates with shift.
Sealing surface

FIG. 2-2-4 FACE-TYPE SEAL

V. PISTON RING SEAL: AS SHOWN IN FIG. 2-2-5.

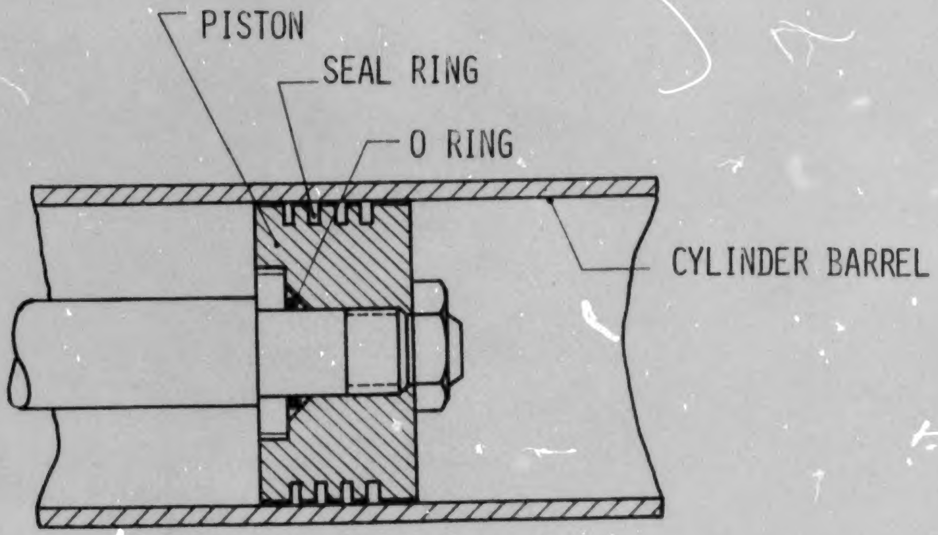


FIG. 2-2-5 PISTON RING SEAL

C. CONDITIONS AFFECTING THE SELECTION OF SEALING DEVICES.

1. SPEED AND FREQUENCY. SPEED IS AN IMPORTANT FACTOR IN DETERMINING FRICTIONAL TEMPERATURES BUILD-UP, WHICH RESULTS IN WEAR OF BOTH THE SEAL AND THE SHAFT. SEALS MAY ALSO BE AFFECTED BY FREQUENCY, DEPENDING UPON THE REVOLUTIONS PER MINUTE.
2. PRESSURE. PRESSURE IN THE SYSTEM IN CONTACT WITH A SEALING DEVICE MAY INCREASE THE CONTACT FORCE. THIS WOULD INCREASE FRICTION, CAUSING HEAT BUILD-UP AND MORE WEAR.
3. TEMPERATURE. THE TEMPERATURE AT THE POINT OF THE SEAL DEPENDS UPON THE MATERIALS IN CONTACT, THE SHAFT SPEED, PRESSURE, AMOUNT OF LUBRICATION, HEAT FROM BEARINGS, HEAT FROM FLUID, OR THEIR SOURCES. THE SEALING DEVICE SELECTED MUST BE UNAFFECTED BY FRICTIONAL TEMPERATURE OR THE FLUID BEING SEALED.
4. COMPATIBILITY. COMPATIBILITY BETWEEN SEALING DEVICES, THE FLUID AND OTHER MATERIALS THAT MAKE THE COMPLETE SYSTEM IS EXTREMELY IMPORTANT. SELECTING THE WRONG SEALING MATERIALS MAY RESULT IN COSTLY SHUTDOWNS AND LOSS OF PRODUCTION.

LESSON PLAN #2

ACCESSORIES OF HYDRAULIC SYSTEMS

ASSIGNMENT SHEET 1

AFTER READING THE INFORMATION SHEET (IS2-2-1) PROVIDED, COMPLETE THE FOLLOWING QUESTIONS IN WRITING OR AS REQUESTED BY YOUR INSTRUCTOR.

1. WHAT IS THE PRIMARY FUNCTION OF A SUCTION LINE FILTER?

2. LIST FIVE METHODS THAT ASSURE THE HYDRAULIC SYSTEM CLEANLINESS.

3. WHEN ROUTING TUBING IN HYDRAULIC SYSTEMS, WHAT KIND OF FACTORS SHOULD BE CONSIDERED?

4. MATCH THE TERMS ON THE RIGHT WITH THE CORRECT DEFINITIONS.

_____ A. A SIMPLE SEAL WITH A ROUND CROSS SECTION.
_____ B. A SEAL WHICH RESEMBLES A SPRING.
_____ C. A THIN FLAT SEAL SANDWICHED BETWEEN TWO METAL SURFACES.
_____ D. ANY DEVICE WHICH KEEPS HYDRAULIC FLUID FROM FLOWING BETWEEN CERTAIN PASSAGES OR KEEPS FOREIGN MATERIALS FROM ENTERING THE SYSTEM.

1. SEALING DEVICES
2. O RING
3. GASKET
4. PACKING

5. LIST FOUR CONDITIONS THAT ARE AFFECTING THE SELECTION OF SEALING DEVICES.

SYLLABUS SHEET FOR LESSON 3
ROBOT SERVICE AND REPAIR

UNIT #2 POWER SUPPLY

DIAGNOSIS AND TESTING

LESSON OBJECTIVE--UPON COMPLETION OF THIS LESSON, THE STUDENT SHOULD BE ABLE TO:

1. VERBALLY EXPLAIN THE FACTORS THAT CAUSE A HYDRAULIC SYSTEM TO HAVE PROBLEMS.
2. VERBALLY DESCRIBE THE PROBLEMS AND REMEDIES CORRECTLY.

TEACHING AIDS:

1. H2-3-1 SYLLABUS SHEET

INFORMATIONAL ASSIGNMENTS:

1. IS2-3-1 DIAGNOSIS AND TESTING
   ANSWER QUESTIONS FOUND ON ASSIGNMENT SHEETS
1. AS2-3-1 DIAGNOSIS AND TESTING

REFERENCES:

PEASE, D.A., BASIC FLUID POWER, PRENTICE-HALL, INC., N.J., 1967.

STEP 1-INTRODUCTION FOR PREPARATION OF THE STUDENT:

IN ORDER TO KEEP A SYSTEM IN A GOOD WORKING CONDITION ALL THE TIME, AN IMPORTANT THING THAT WE SHOULD KEEP IN MIND IS THAT A GOOD PREVENTIVE MAINTENANCE PROGRAM SHOULD BE ESTABLISHED. THIS KIND OF PROGRAM INCLUDES KEEPING GOOD RECORDS, CONTINUOUS INSPECTION OF EQUIPMENT, AND HEADING OFF DIFFICULTIES THROUGH SYSTEM CLEANLINESS AND MAKING MINOR REPAIRS BEFORE THEY BECOME MAJOR REPAIRS WITH COSTLY DOWN TIME. HOWEVER, IF A PROBLEM HAPPENED, WE WOULD BE ABLE TO DETECT IT AND REMEDY IT.

IN THIS UNIT THE STUDENT WILL LEARN AND KNOW WHAT PROBLEMS WILL BE HAPPENING IN A SYSTEM AND HOW TO DIAGNOSE AND TEST IT. LAST OF ALL, THE STUDENT WILL HAVE THE CAPABILITY TO KNOW HOW TO REMEDY IT.

LESSON SUMMARY AND REVIEW:

1. IN ORDER TO PREVENT DELAY AND DOWN TIME IN A MAINTENANCE SCHEDULE, WHAT SHOULD WE CONSIDER?

2. IF THE OIL LEAK IN A PRESSURE LINE SHOULD OCCUR, WHAT WILL HAPPEN AND WHAT DO YOU DO FOR IT?

3. WHAT PROBLEMS WILL CAUSE THE SYSTEM TO RUN TOO FAST?

4. WHAT PROBLEMS CAN CAUSE THE PUMP TO LEAK?

5. IN WHAT KIND OF SITUATIONS WILL THE CONTROL VALVE STICK OR WORK HARD?

DIAGNOSIS AND TESTING

1. THE TOOLS OF GOOD MAINTENANCE.

THERE ARE FOUR ITEMS WHICH SHOULD BE OF CONCERN IN DEALING WITH MAINTENANCE OF A HYDRAULIC SYSTEM:

A. EQUIPMENT MANUALS, BLUEPRINTS, DATA SHEETS, PARTS, LISTS, AND OTHER SUCH INFORMATION.

B. AN ADEQUATE TESTING FACILITY TO BENCH-TEST PUMPS, CONTROLS, AND ACTUATORS THAT HAVE UNDERGONE REPAIR. IT MAY BE DANGEROUS TO TEST REPAIRED COMPONENTS DIRECTLY ON HIGH-PRODUCTION TYPE MACHINERY.

C. ADEQUATE TOOLS, SUCH AS ACCURATE PRESSURE GAUGES, FLOW METERS, CLEAN WORKING SPACE, HAND TOOLS, HOISTS, TOTE CARTS, ETC., ARE NEEDED.

D. GOOD INVENTORY OF SPARE PARTS, SUCH AS SEALS, BEARINGS, REPAIR KITS, EXTRA HYDRAULIC FLUID, FILTER CARTRIDGES, AND MOST IMPORTANT, SPARE COMPONENTS.

2. PROBLEMS CAUSE AN INOPERATIVE SYSTEM AND CORRECT REMEDIES.

ITEMS	PROBLEMS	REMEDIES
A.	NO OIL IN SYSTEM	-FILL TO FULL MARK -CHECK SYSTEM FOR LEAKS
B.	OIL LOW IN RESERVOIR	-CHECK LEVEL AND FILL TO FULL -CHECK SYSTEM FOR LEAKS
C.	FILTER DIRTY OR PLUGGED	-DRAIN OIL AND REPLACE FILTERS -TRY TO FIND SOURCE OF CONTAMINATION
D.	RESTRICTION IN SYSTEM	-OIL LINES COULD BE DIRTY OR HAVE INNER WALLS THAT ARE COLLAPSING TO CUT OFF OIL SUPPLY -CLEAN OR REPLACE LINES -CLEAN ORIFICES

ITEMS	PROBLEMS	REMEDIES
E.	AIR LEAKS IN PUMP SUCTION LINE	-REPAIR OR REPLACE LINES
F.	BADLY WORN COMPONENT	-EXAMINE AND TEST -REPAIR OR REPLACE IT
G.	OIL LEAK IN PRESSURE LINES	-TIGHTEN FITTINGS OR REPLACE DEFECTIVE LINES -EXAMINE MATING SURFACES ON COUPLERS FOR IRREGULARITIES
H.	OPERATING SYSTEM UNDER EXCESSIVE LOAD	-CHECK SPECIFICATIONS OF UNIT FOR LOAD LIMITS
I.	SLIPPING OR BROKEN PUMP DRIVE	-REPLACE COUPLERS OR BELTS IF NECESSARY -ALIGN THEM AND ADJUST TENSION
J.	PUMP NOT OPERATING	-CHECK FOR SHUT-OFF DEVICE ON PUMP OR PUMP DRIVE

3. PROBLEM WHICH CAUSE A SYSTEM TO OPERATE ERRATICALLY AND CORRECT REMEDIES.

ITEMS	PROBLEMS	REMEDIES
A.	AIR IN SYSTEM	-EXAMINE SUCTION SIDE OF THE SYSTEM FOR LEAKS -MAKE SURE OIL LEVEL IS CORRECT
B.	COMPONENTS STICKING OR BINDING	-CHECK FOR DIRT OR GUMMY DEPOSITS, AND IF DIRT IS CAUSED BY CONTAMINATION, TRY TO FIND THE SOURCE -CHECK FOR WORN OR BENT PARTS
C.	DIRT IN RELIEF VALVES	-CLEAN RELIEF VALVES
D.	RESTRICTION IN FILTER OR SUCTION LINE	-SUCTION LINE DIRTY -CLEAN OR REPLACE IT -CHECK FILTER LINE FOR RESTRICTIONS

4. PROBLEMS WHICH CAUSE A SYSTEM TO OPERATE SLOWLY AND REMEDIES.

ITEMS	PROBLEMS	REMEDIES
A.	COLD OIL	-WARM UP OIL
B.	OIL VISCOSITY TOO HEAVY	-USE OIL RECOMMENDED BY THE MANUFACTURER
C.	LOW OIL SUPPLY	-CHECK RESERVOIR AND ADD OIL IF NECESSARY -CHECK SYSTEM FOR LEAKS THAT COULD CAUSE LOSS OF OIL

ITEMS	PROBLEMS	REMEDIES
D.	AIR IN THE SYSTEM	-CHECK SUCTION SIDE OF THE SYSTEM FOR LEAKS
E.	BADLY WORN PUMP	-REPAIR OR REPLACE PUMP -CHECK FOR PROBLEMS CAUSING PUMP WEAR
F.	RELIEF VALVE NOT PROPERLY SET OR LEAKING	-TEST RELIEF VALVES -EXAMINE VALVES FOR DAMAGED SEATS THAT COULD LEAK
G.	RESTRICTION IN SUCTION LINE OR FILTER	-SUCTION LINE DIRTY -CLEAN OR REPLACE SUCTION LINE -EXAMINE FILTER FOR PLUGGING
H.	BADLY WORN COMPONENTS	-EXAMINE AND TEST VALVES, MOTORS, CYLINDERS, AND ETC. -IF WEAR IS ABNORMAL, TRY TO LOCATE THE CAUSE
I.	VALVE OR REGULATOR PLUGGED	-CLEAN DIRT FROM COMPONENTS -CLEAN ORIFICES -CHECK SOURCE OF DIRT AND CORRECT
J.	OIL LEAK IN PRESSURE LINES	-TIGHTEN FITTING OR REPLACE DEFECTIVE LINES -EXAMINE MATING SURFACES ON COUPLERS FOR IRREGULARITIES

5. PROBLEMS WHICH CAUSE THE SYSTEM TO OPERATE TOO FAST AND THE REMEDIES.

ITEMS	PROBLEMS	REMEDIES
A.	ADJUSTABLE ORIFICE INSTALLED BACKWARD OR NOT INSTALLED	-INSTALL ORIFICE PARTS CORRECTLY AND ADJUST
B.	OBSTRUCTION OR DIRT UNDER SEAT OF ORIFICE	-REMOVE FOREIGN MATERIAL AND READJUST ORIFICE

6. PROBLEMS WHICH CAUSE THE SYSTEM TO OVERHEAT AND THE REMEDIES.

ITEMS	PROBLEMS	REMEDIES
A.	USING INCORRECT OIL	-USE OIL RECOMMENDED BY THE MANUFACTURER -BE SURE OIL VISCOSITY IS CORRECT
B.	LOW OIL LEVEL	-FILL RESERVOIR -LOOK FOR LEAKS
C.	DIRTY OIL	-DRAIN AND REFILL WITH CLEAN OIL -LOOK FOR SOURCE OF CONTAMINATION
D.	INCORRECT RELIEF VALVE PRESSURE	-EXAMINE AND TEST VALVES, CYLINDERS, MOTORS, ETC. FOR EXTERNAL OR INTERNAL LEAKS
E.	RESTRICTION IN PUMP SUCTION LINE	-CLEAN OR REPLACE IT

ITEMS	PROBLEMS	REMEDIES
F.	HEAT NOT RADIATING PROPERLY	-CLEAN DIRT AND MUD FROM RESERVOIR, OIL LINES, COOLERS AND OTHER COMPONENTS

7. PROBLEMS WHICH MAKE THE PUMP TOO NOISY AND THE REMEDIES.

ITEMS	PROBLEMS	REMEDIES
A.	LOW FLUID LEVEL	-FILL RESERVOIR -CHECK SYSTEM FOR LEAKS
B.	FLUID VISCOSITY TOO HIGH	-CHANGE FLUID
C.	PUMP SPEED TOO FAST	-OPERATE PUMP SPEED PROPERLY
D.	SLUDGE AND DIRT IN PUMP	-DISASSEMBLE AND INSPECT PUMP AND LINES -CLEAN HYDRAULIC SYSTEM -DETERMINE CAUSE OF DIRT
E.	AIR IN FLUID	-TIGHTEN OR REPLACE SUCTION LINE -CHECK SYSTEM FOR LEAKS -REPLACE PUMP SHAFT SEAL
F.	BROKEN OR DAMAGED PUMP PARTS	-REPAIR PUMP -LOOK FOR CAUSE OF DAMAGE
G.	STICKING OR BINDING PARTS	-REPAIR BINDING PARTS -CLEAN PARTS AND CHANGE FLUID IF NECESSARY

8. PROBLEMS WHICH CAUSE THE PUMP TO LEAK AND THE REMEDIES.

ITEMS	PROBLEMS	REMEDIES
A.	DAMAGE SEAL AROUND DRIVE SHAFT	-TIGHTEN PACKING OR REPLACE SEAL
B.	LOOSE OR BROKEN PUMP PARTS	-TIGHTEN OR REPLACE PARTS

9. PROBLEMS WHICH CAUSE THE POWER STEERING TO FUNCTION IMPROPERLY AND THE REMEDIES.

ITEMS	PROBLEMS	REMEDIES
A.	AIR IN SYSTEM	-BLEED SYSTEM -CHECK FOR AIR LEAKS
B.	INTERNAL LEAKAGE IN SYSTEM	-COMPONENTS MAY NOT BE ADJUSTED PROPERLY -PARTS MAY BE WORN OR BROKEN -CHECK FOR CAUSE OF WEAR
C.	SYSTEM NOT PROPERLY TIMED	-TIME AGAIN
D.	INSUFFICIENT PRESSURE	-CHECK PUMP AND RELIEF VALVES -CONTAMINATION COULD CAUSE VALVES TO LEAK OR PUMP TO WEAR

10. FACTORS THAT CAUSE A SYSTEM PROBLEMS.

ITEMS	PROBLEMS	FACTORS
A.	CAUSE THE CONTROL VALVE TO STICK OR WORK HARD	-MISALIGNMENT OR SEIZING OF OF CONTROL LINKAGE -TIE BOLTS TOO TIGHT -VALVE BROKEN OR SCARRED INTERNALLY
B.	CAUSE THE CONTROL VALVE TO LEAK	-TIE BOLTS TOO LOOSE -WORN OR DAMAGED O-RINGS -BROKEN VALVE PARTS
C.	CAUSE A CYLINDER TO LEAK	-DAMAGED CYLINDER BARREL -ROD SEAL LEAKING -LOOSE PARTS -PISTON ROD DAMAGED

LESSON PLAN #3

POWER SUPPLY

ASSIGNMENT SHEET 1

AFTER READING THE INFORMATION SHEET (IS2-3-1) PROVIDED, COMPLETE THE FOLLOWING QUESTIONS IN WRITING OR AS REQUESTED BY YOUR INSTRUCTOR.

1. MATCH THE PROBLEMS WHICH MAY CAUSE AN INOPERATIVE SYSTEM ON THE RIGHT WITH THE CORRECT REMEDIES.

____ A. -FILL TO FULL MARK
-CHECK SYSTEM FOR LEAKS

____ B. -CLEAN AND REPAIR PUMP
-DRAIN AND FLUSH HYDRAULIC SYSTEM, IF NECESSARY
-TRY TO FIND SOURCE OF CONTAMINATION

____ C. -DRAIN OIL AND REPLACE FILTERS
-TRY TO FIND SOURCE OF CONTAMINATION

____ D. -REPAIR OR REPLACE LINE

____ E. -EXAMINE AND TEST VALVES, MOTORS, CYLINDERS, ETC., FOR EXTERNAL AND INTERNAL LEAKS

1. DIRT IN PUMP
2. RELIEF VALVE DEFECTIVE
3. AIR LEAK IN PUMP SUCTION LINE
4. NO OIL IN SYSTEM
5. FILTER DIRTY OR PLUGGED

2. LIST TWO PROBLEMS WHICH MAY CAUSE THE SYSTEM TO OPERATE TOO FAST.

3. WHAT KINDS OF PROBLEMS MAY CAUSE THE SYSTEM TO OVER HEAT? LIST FIVE.

4. SELECT THE PROBLEMS THAT MAY CAUSE A CONTROL VALVE TO LEAK BY PLACING A "V" IN THE APPROPRIATE BLANKS.

____ A. TIE BOLTS TOO LOOSE
____ B. BROKEN VALVE PARTS
____ C. CRACKED RESERVOIR
____ D. WORN OR DAMAGED O-RING
____ E. OIL LEVELTOO LOW
____ F. AIR IN FLUID

5. WHAT KINDS OF PROBLEMS WILL CAUSE A CYLINDER TO LEAK?

SYLLABUS SHEET FOR LESSON 4
ROBOT SERVICE AND REPAIR

UNIT #2 POWER SUPPLY

PNEUMATIC SYSTEM

LESSON OBJECTIVE--UPON COMPLETION OF THIS LESSON, THE STUDENT SHOULD BE ABLE TO:

1. VERBALLY COMPARE THE PNEUMATIC SYSTEM AND THE HYDRAULIC SYSTEM.
2. VERBALLY DESCRIBE THE VARIETY OF PNEUMATIC SYSTEM COMPONENTS AND THEIR FUNCTIONS.

TEACHING AIDS:

1. H2-4-1 SYLLABUS SHEET
2. T2-4-1 COMPARISON OF PNEUMATIC AND HYDRAULIC SYSTEMS
3. T2-4-2 BASIC PNEUMATIC SYSTEM
4. T2-4-3 ACTUATOR

INFORMATIONAL ASSIGNMENTS:

1. IS2-4-1 INTRODUCTION
2. IS2-4-2 PNEUMATIC SYSTEM COMPONENTS

ANSWER QUESTIONS FOUND ON THE ABOVE ASSIGNMENT SHEETS

1. AS2-4-1 PNEUMATIC SYSTEM

REFERENCES:

JOHNSON, O.A., FLUID POWER-PNEUMATICS, AMERICAN TECHNICAL SOCIETY, CHICAGO, 1975.

PEASE, D.A., BASIC FLUID POWER, PRENTICE-HALL, INC., N.J., 1967.

STEP 1-INTRODUCTION FOR PREPARATION OF THE STUDENT:

A PNEUMATIC SYSTEM IS VERY SIMILAR BOTH IN ITS CONSTRUCTION AND OPERATION TO THE HYDRAULIC SYSTEM. WHEREAS, THE HYDRAULIC SYSTEM USES A NON-COMPRESSIBLE FLUID TO TRANSMIT A FORCE BETWEEN THE SOURCE AND THE LOAD. A PNEUMATIC SYSTEM USES COMPRESSIBLE AIR TO PERFORM THE SAME FUNCTION. THEY ARE WIDELY USED IN A VARIETY OF INDUSTRIAL APPLICATIONS. TODAY, OWNING THE AIR IS CONVENIENT AND UNIVERSALLY AVAILABLE. MOST MANUFACTURING AND PROCESSING PLANTS ARE EQUIPPED TO MAINTAIN AIR FOR A VARIETY OF OPERATIONS.

IN THIS LESSON, THE STUDENT WILL LEARN AND KNOW THE BASIC PNEUMATIC SYSTEM AND ITS RELATED COMPONENTS USED IN THE SYSTEM.

LESSON SUMMARY AND REVIEW:

1. WHAT KIND OF DEVICE IS REQUIRED IN USING THE PNEUMATIC SYSTEM?

2. THERE ARE TWO MAIN CATEGORIES OF COMPRESSORS. WHAT ARE THEY?

3. WHAT ARE THE BASIC FUNCTIONS OF A PNEUMATIC VALVE?

4. IN A PNEUMATIC SYSTEM, IF THE PRESSURE AIR CONTAINS TOO MUCH MOISTURE, WHAT SITUATION WILL HAPPEN?

5. WHAT IS THE PURPOSE OF USING A MUFFLER IN A PNEUMATIC SYSTEM?

INTRODUCTION

A PNEUMATIC SYSTEM IS VERY SIMILAR TO THE HYDRAULIC SYSTEM IN CONSTRUCTION OR OPERATION. THE MAIN DIFFERENCE BETWEEN APPLYING PNEUMATIC AND HYDRAULIC FLUID POWER IS THE COMPRESSIBILITY FACTOR OF THE TWO MEDIA. THAT MEANS THE HYDRAULIC SYSTEM USED A NON-COMPRESSIBLE FLUID TO TRANSMIT A FORCE BETWEEN THE SOURCE AND THE LOAD. A PNEUMATIC SYSTEM USES COMPRESSIBLE AIR TO PERFORM THE SAME FUNCTION. BEFORE WE GET IN TO THE DISCUSSION OF A PNEUMATIC SYSTEM, LET US TAKE A FEW MINUTES TO COMPARE SOME OF THE DIFFERENCES BETWEEN THE TWO SYSTEMS.

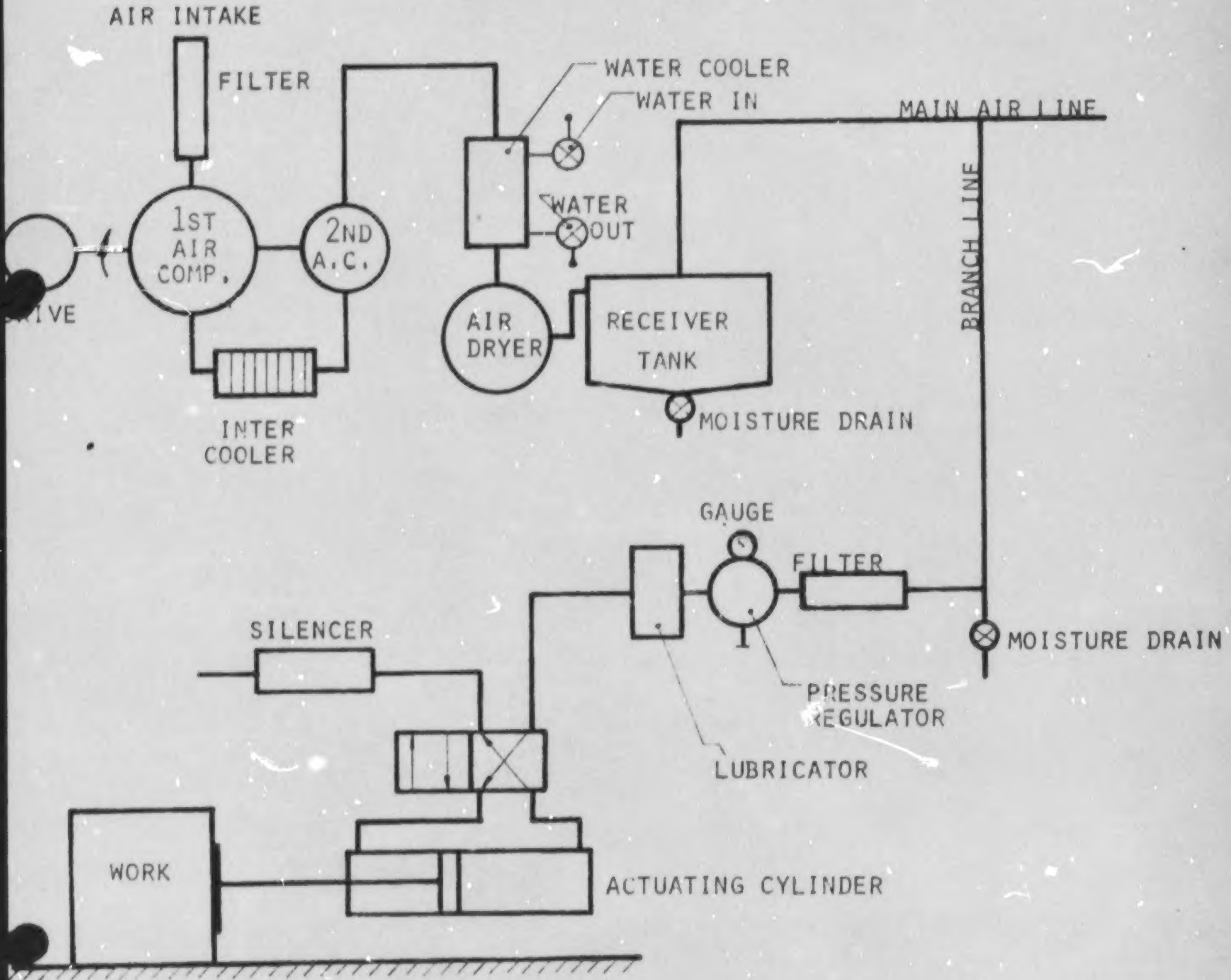
1. COMPARISON OF PNEUMATIC AND HYDRAULIC SYSTEM

ITEM OF COMPARISON	PNEUMATIC	HYDRAULIC
RELIABILITY	VERY GOOD	VERY GOOD
POSITIONING ACCURACY	VERY GOOD	VERY GOOD
LOAD	LIGHT	HEAVY
COST	LESS EXPENSIVE	MORE EXPENSIVE
MEDIA	GASEOUS	LIQUID
EQUIPMENT REQUIRED	LUBRICATING DEVICE	LUBRICATION NO PROBLEM
WORKING PART	LARGER	SMALLER

2. BASIC PNEUMATIC SYSTEM.

SHOWN IN FIGURE 2-4-1 IS A TYPICAL AIR SYSTEM AND SOME OF THE EQUIPMENT THAT IS VERY SIMILAR TO THE HYDRAULIC SYSTEM WE DISCUSSED BEFORE. AS WE PROCEED WITH OUR DISCUSSION OF THE PNEUMATIC SYSTEM, WE WILL SEE THAT MANY OF THE COMPONENTS HAVE THE SAME NAME AND PERFORM THE SAME TASK AS THEY DID IN THE HYDRAULIC SYSTEM.

FIG. 2-4-1
BASIC PNEUMATIC SYSTEM


AIR INTAKE
FILTER
1ST AIR COMP.
2ND A.C.
IVE
INTER COOLER
WATER COOLER
WATER IN
WATER OUT
AIR DRYER
RECEIVER TANK
MOISTURE DRAIN
MAIN AIR LINE
BRANCH LINE
GAUGE
FILTER
MOISTURE DRAIN
PRESSURE REGULATOR
LUBRICATOR
SILENCER
WORK
ACTUATING CYLINDER

IN FIGURE 2-4-1, FREE AIR FROM THE ATMOSPHERE ENTERS THE COMPRESSOR THROUGH A FILTER, WHICH IS ESSENTIAL TO KEEP DUST AND CONTAMINATION FROM ENTERING THE SYSTEM. THE AIR PASSES FROM THE FIRST COMPRESSIVE STEP THROUGH AN INTERCOOLER, WHERE IT LOSES SOME OF ITS HEAT OF COMPRESSION BEFORE ENTERING THE SECOND STAGE. HIGH PRESSURE AIR DISCHARGED FROM THE SECOND STAGE THEN PASSES THROUGH THE WATER COOLER TO THE AIR DRIER. FROM THE DRIER AIR PASSES INTO THE RESERVOIR, WHERE IT IS STORED AS PRESSURE ENERGY UNTIL IT IS NEEDED BY THE PNEUMATIC CIRCUIT.

WHEN THE CONTROL VALVE IS ENERGIZED, THE AIR PASSES FROM THE MAIN LINE THROUGH A FILTER, REGULATOR, AND LUBRICATOR COMBINATION UNIT BEFORE ENTERING THE CYLINDER TO DO WORK. IF SEVERAL SYSTEMS ARE BEING SUPPLIED FROM ONE MAIN LINE AIR SOURCE, PRESSURE REDUCING VALVES WOULD BE NEEDED TO SUPPLY EACH SYSTEM WITH THE DESIRED PRESSURE.

PNEUMATIC SYSTEM COMPONENTS

1. AIR COMPRESSOR.

AIR COMPRESSORS ARE PUMPS. THEY ARE INTENDED TO SUPPLY CLEAN, DRY AIR TO WORK STATIONS. THEY DRAW AIR IN THROUGH THE INTAKE, COMPRESS IT WHICH RAISES ITS PRESSURE AND TEMPERATURE, AND THEN STORE IT IN A RESERVOIR.

THERE ARE TWO MAIN CATEGORIES OF COMPRESSORS; POSITIVE DISPLACEMENT COMPRESSORS AND DYNAMIC COMPRESSORS.

POSITIVE DISPLACEMENT COMPRESSORS ARE EXTENSIVELY USED FOR INDUSTRIAL PROCESSES WHERE THE GAS IS USED AS A MEDIUM FOR TRANSMITTING POWER. THEY **COMPRESS THE** GASEOUS MEDIUM TO A HIGHER PRESSURE BY POSITIVELY CONFINING IT IN A GRADUALLY DECREASING SPACE AND ROUTE IT TO THE AIR STORAGE TANK THAT ACTS AS A RESERVOIR FOR THE COMPRESSED AIR.

2. RESERVOIRS OR STORAGE TANKS.

A STORAGE TANK ACTS AS A RESERVOIR FOR THE COMPRESSED AIR. THEY ARE DESIGNED FOR PRESSURES FROM 32 PSI TO 273 PSI. SPECIAL DESIGNS HAVE, HOWEVER, BEEN CONSTRUCTED FOR PRESSURES UP TO 450 PSI. USUALLY, A RELIEF VALVE MUST BE ATTACHED TO THE PRESSURIZED TANKS, SO THAT THE RELIEF VALVE CAN BE INSPECTED WITH GAS IN THE TANK FOR THE SAFETY PURPOSE.

3. VALVES.

PNEUMATIC VALVES ARE USED TO REGULATE THE PRESSURE AIR VELOCITY FLOW RATE AND MANAGE THE DIRECTION OF THE FLUID. PRESSURE RELIEF VALVES PROTECT THE COMPRESSOR AND COMPONENTS BY SETTING THE MAXIMUM SYSTEM PRESSURE WITHIN SAFE WORKING LIMITS. PRESSURE CONTROL VALVES, USUALLY CALLED AIR LINE REGULATORS, AS SHOWN IN FIGURE 2-4-2, ARE INSTALLED AT OR NEAR THE PRESSURE DROP FROM THE MAIN TRANSMISSION LINE AND ESTABLISH THE WORKING PRESSURE OF THE BRANCH CIRCUIT.

DIRECTIONAL CONTROL VALVES ARE USED TO STOP, START, DIVERT, SHUTTLE, AND OTHERWISE MANAGE THE DIRECTION OF THE FLUID (AIR) IN TWO, THREE, FOUR, AND OTHER WAYS TO EFFECT THE DESIRED DIRECTION OF COMPONENT MOVEMENT, AS SHOWN IN FIGURE 2-4-3, 2-4-4, AND 2-4-5.

FIG. 2-4-2
PRESSURE REGULATOR

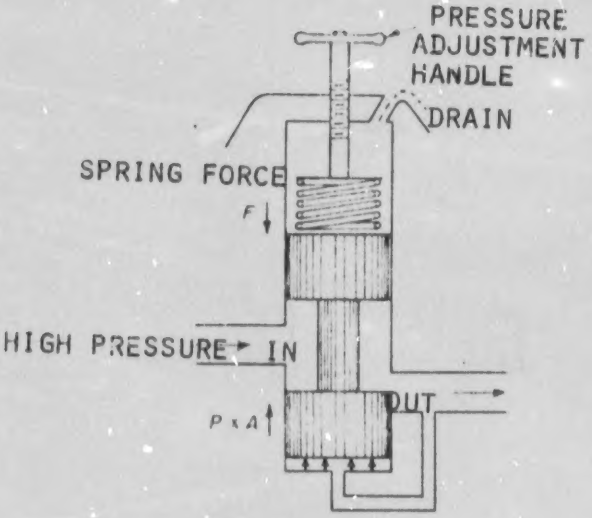

PRESSURE
ADJUSTMENT
HANDLE
DRAIN
SPRING FORCE
F
HIGH PRESSURE IN
OUT
P x A

FIG. 2-4-3
2-WAY CONTROL VALVE

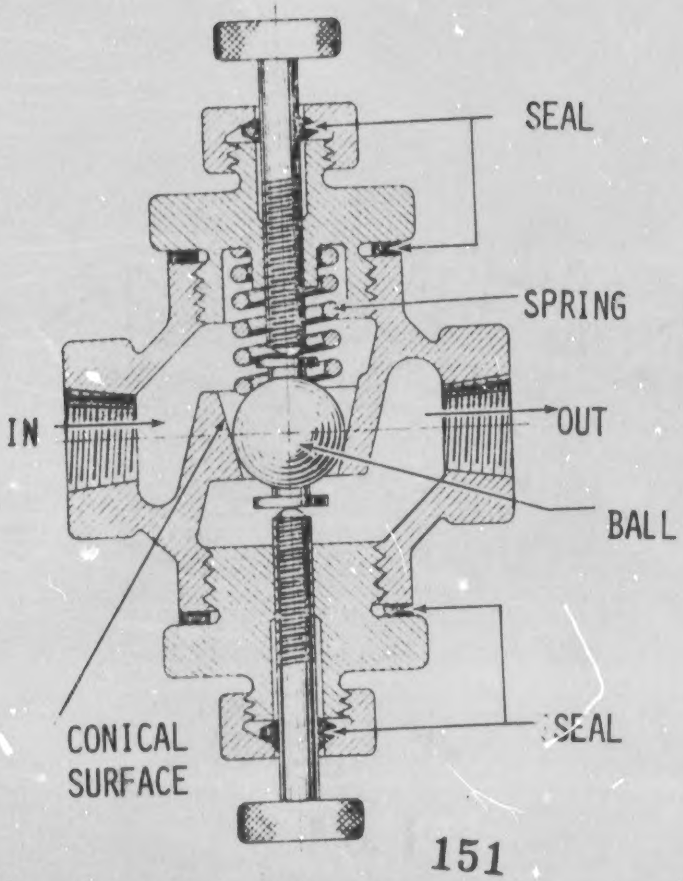

SEAL
SPRING
IN
OUT
BALL
SEAL
CONICAL
SURFACE

FIG. 2-4-4
3-WAY VALVE

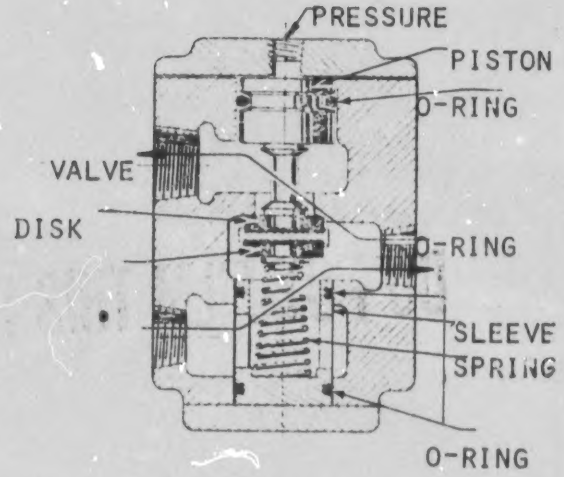
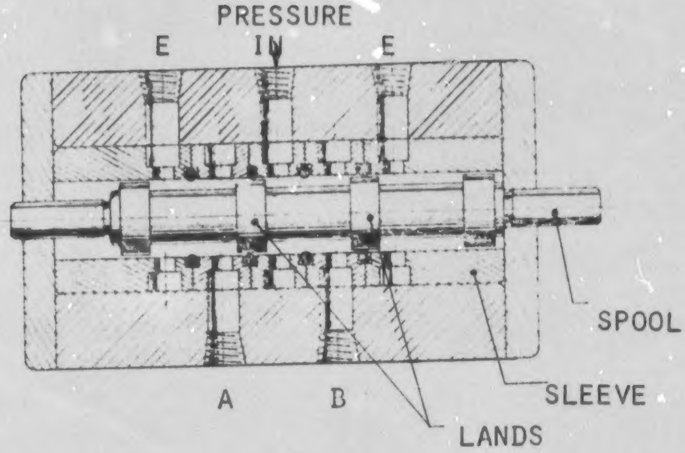

PRESSURE
PISTON
O-RING
VALVE
DISK
O-RING
SLEEVE
SPRING
O-RING

FIG. 2-4-5
4-WAY VALVE


PRESSURE
E
IN
E
SPOOL
SLEEVE
A
B
LANDS

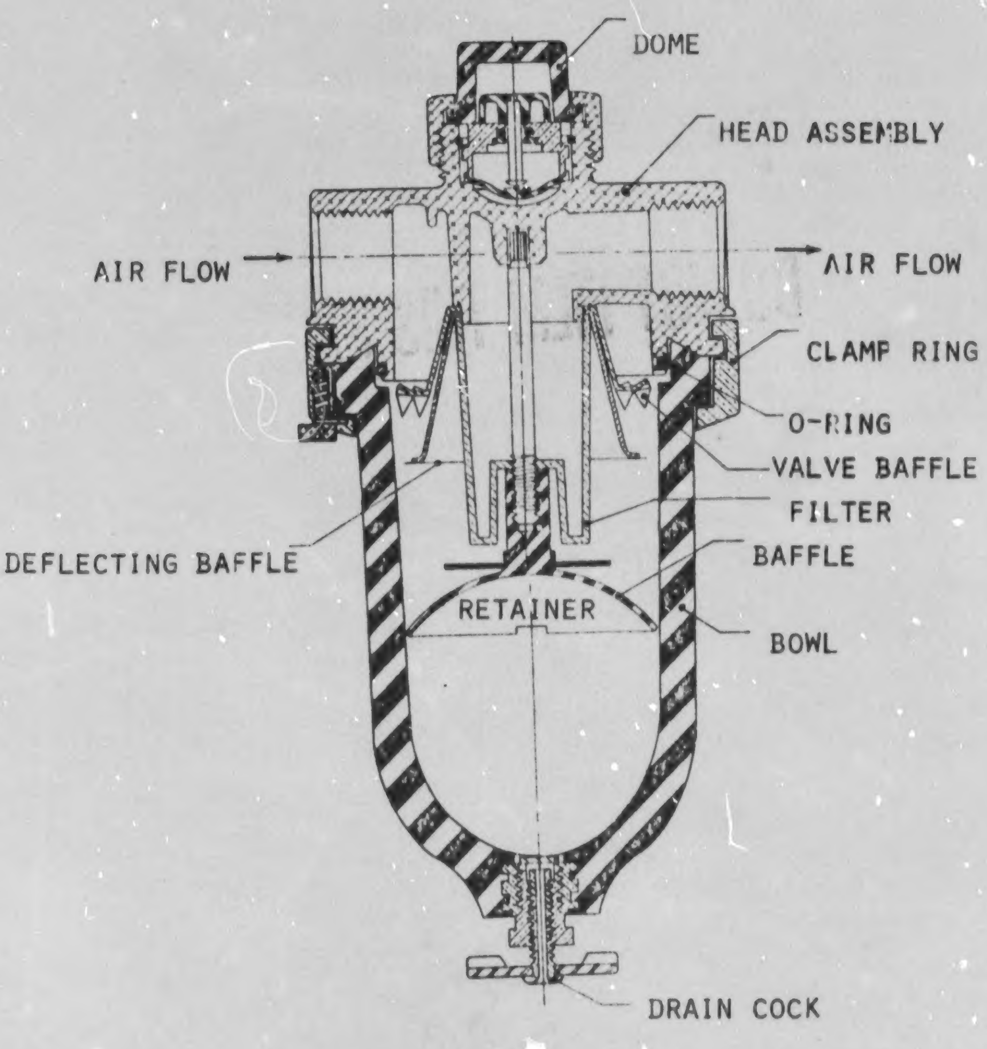
4. AIR CONDITIONING UNIT

THE AIR CONDITIONING UNIT TREATS THE COMPRESSED AIR MORE ACCEPTABLE AS A MEDIUM TO THE SYSTEM AND OPERATING PERSONNEL. THIS UNIT TAKES THE COMPRESSED AIR FROM THE STORAGE TANK AND REMOVES ANY DIRT AND MOISTURE CONTAINED IN THE AIR. THEY CONSIST OF FILTERS, MOISTURE SEPARATERS, AIR DRIERS, LUBRICATORS AND MUFFLERS. IMPROPERLY CONDITIONED FLUID AIR USED IN A SYSTEM CAN CAUSE THE SYSTEM FAILURE AND COSTLY REPAIRS.

A. AIR FILTERS.

THE AIR FILTERS ARE LOCATED IN THE COMPRESSOR INTAKE IN THE PRESSURE LINE BEFORE COMPONENTS, AND IMMEDIATELY PROCEEDING POWER TOOLS. THEY PROTECT AGAINST CATASTROPHIC FAILURE FROM LARGE PARTICLES AS WELL AS GRADUAL FAILURE FROM SMALL PARTICLES THAT PROMOTE WEAR BY LAPPING ACTION USING DIRT AND OTHER FINE PASTICULATE MATTER AS AN ABRASIVE AGENT. IF THE FILTERIS IN IMPROPER CONDITION,IT WILL RESULT IN REDUCED VOLUMETRIC AND PUMPING EFFICIENCY, AS SHOWN IN FIGURE 2-4-6.

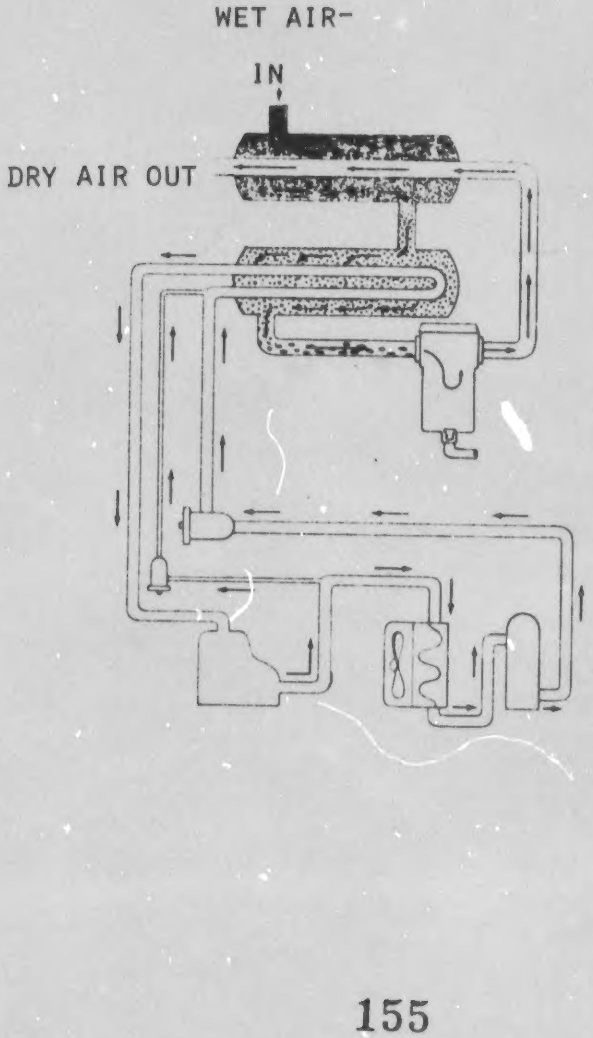
FIG. 2-4-6
AIR FILTER


DOME
HEAD ASSEMBLY
AIR FLOW
AIR FLOW
CLAMP RING
O-RING
VALVE BAFFLE
FILTER
DEFLECTING BAFFLE
BAFFLE
RETAINER
BOWL
DRAIN COCK

B. MOISTURE SEPARATORS AND AIR DRIERS.

USUALLY THE DRY AIR IS REQUIRED BY A PNEUMATIC SYSTEM. THE AIR USED IN A SYSTEM CONTAINING EXCESSIVE MOISTURE CAN CAUSE OXIDATION OF PLUMBING AND COMPONENT SEIZING, RESULTING IN ERRATIC OPERATION FAILURE, DOWNTIME, AND COSTLY REPAIR. TO REMOVE MOISTURE, THE AIR MAY BE REFRIGERATED, HEATED OR PASSED THROUGH DESICCANTS WHICH REMOVE OIL AND WATER VAPORS. AS SHOWN IN FIGURE 2-4-7, IS A KIND OF MOISTURE REMOVER.

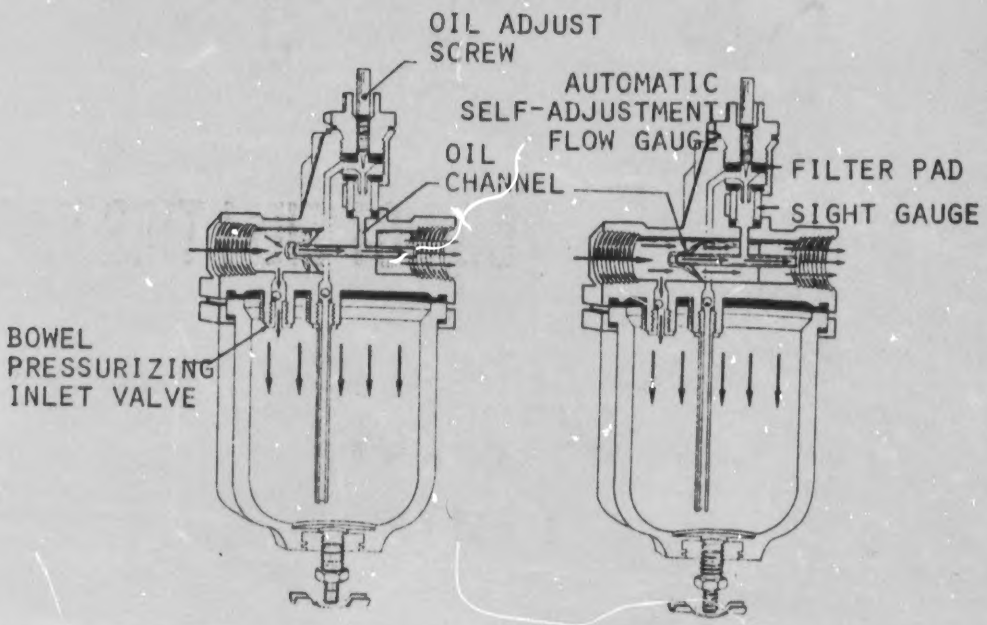
FIG. 2-4-7
REFRIGERATED DRYER CYCLE



C. LUBRICATOR.

LUBRICATORS ARE USED TO ASSURE PROPER LUBRICATION OF INTEGRAL MOVING PARTS OF PNEUMATIC COMPONENTS. SHOWN IN FIGURE 2-4-8, IS ONE KIND OF A LUBRICATOR.

FIG. 2-4-8
LUBRICATORS


OIL ADJUST SCREW
AUTOMATIC SELF-ADJUSTMENT FLOW GAUGE
OIL CHANNEL
FILTER PAD
SIGHT GAUGE
BOWEL PRESSURIZING INLET VALVE

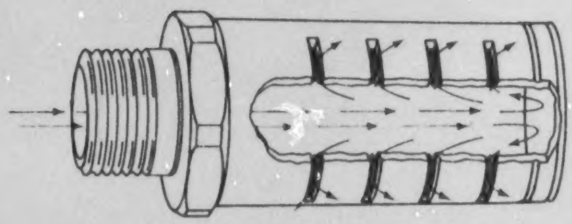
LOW
AIR FLOW

HIGH
AIR FLOW

D. MUFFLERS.

MUFFLERS ARE MOUNTED TO THE EXHAUST PORTS OF AIR VALVE, CYLINDERS, AND AIR MOTORS TO REDUCE NOISE AND ELIMINATE THE POSSIBILITY THAT THE AIR STREAM OR AIRBORNE PARTICLES WILL CAUSE INJURY TO PERSONNEL. MUFFLER CALLED SILENCER ALSO AS SHOWN IN FIGURE 2-4-9

FIG. 2-4-9
MUFFLER



5. ACTUATOR.

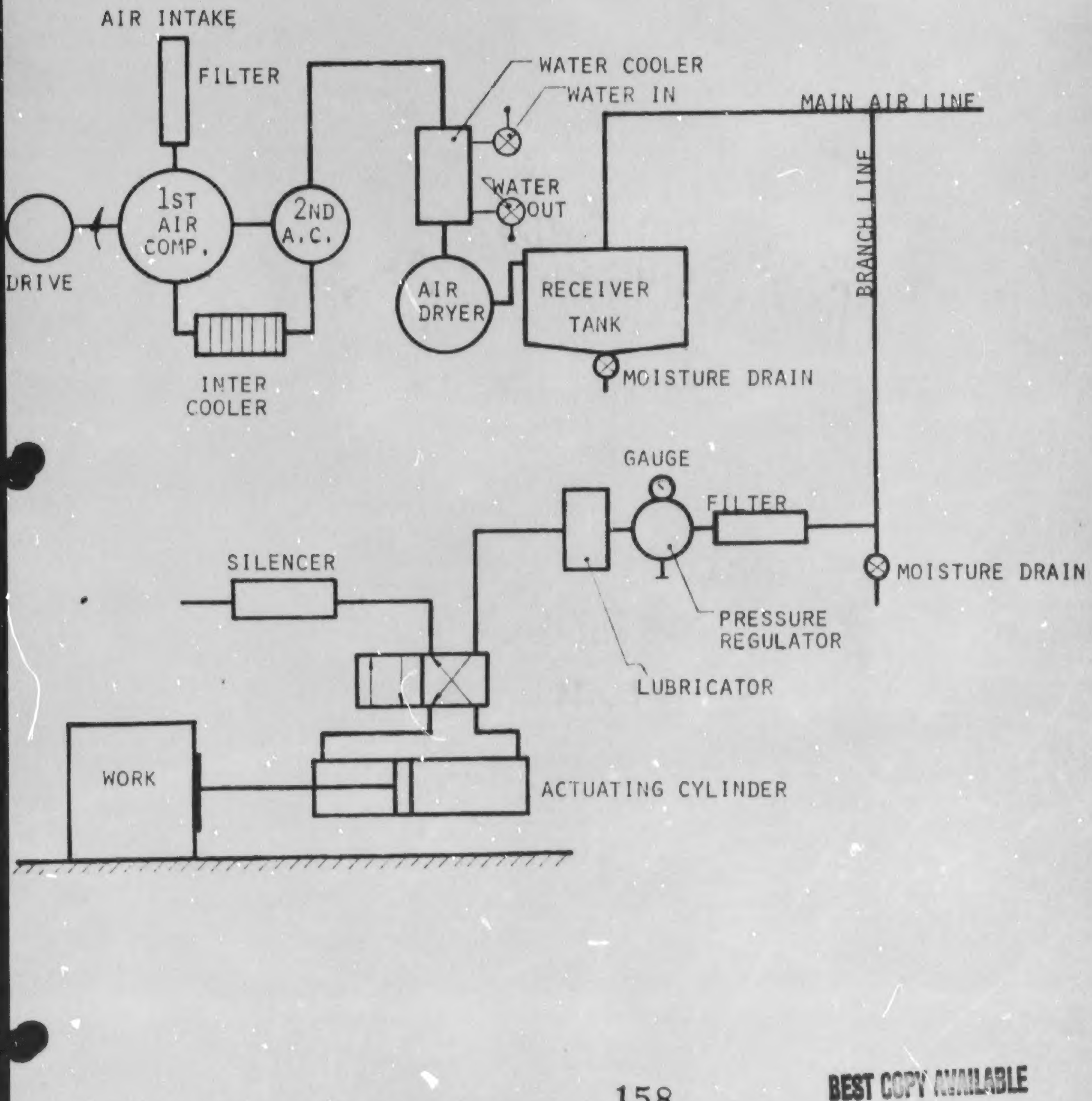
AS DISCUSSED IN HYDRAULIC SYSTEM, A CONTROL VALVE AND AN ACTUATOR WORK HAND IN HAND TO POSITION A LOAD. SHOWN IN FIGURE 2-4-10 IS A SIMPLE PNEUMATIC CONTROL CIRCUIT OF A 4-WAY CONTROL VALVE TO POSITION A DOUBLE ACTING ACTUATOR.

IN THIS ILLUSTRATION, WHEN THE HANDLE IS PLACED IN THE DOWN POSITION, THE VALVE SPOOLS ALSO MOVE DOWN. THIS PERMITS COMPRESSED AIR TO FLOW FROM PORT P THROUGH CONTROL VALVE INTO PORT A OF THE ACTUATOR. THEN THE COMPRESSED AIR FORCES THE ACTUATOR PISTON DOWN WHICH IN TURN FORCES AIR OUT OF THE ACTUATOR THROUGH PORT B. BECAUSE OF THE POSITION OF THE CONTROL VALVE SPOOLS, THE AIR FORCED OUT OF THE ACTUATOR IS ALLOWED TO FLOW INTO THE B OF THE CONTROL VALVE, AND OUT OF PORT E1 TO THE ATMOSPHERE.

IN REVERSE, THE CONTROL HANDLE IS PLACED IN THE UP POSITION, THEN THE AIR WILL VENT INTO THE ATMOSPHERE FROM E2. WHEN THE CONTROL HANDLE IS PLACED IN THE OFF POSITION, AS SEEN IN THE ILLUSTRATION, ALL CONTROL VALVE PORTS ARE BLOCKED, THUS, NO WORK AT ALL.

AS IN THE HYDRAULIC SYSTEM, VARIOUS TYPES OF CONTROL VALVES AND ACTUATORS CAN BE USED, DEPENDING ON THE JOB TO BE PERFORMED.

FIG. 2-4-10
ACTUATOR


AIR INTAKE
FILTER
WATER COOLER
WATER IN
MAIN AIR LINE
1ST AIR COMP.
2ND A.C.
WATER OUT
DRIVE
AIR DRYER
RECEIVER TANK
BRANCH LINE
INTER COOLER
MOISTURE DRAIN
GAUGE
FILTER
SILENCER
MOISTURE DRAIN
PRESSURE REGULATOR
LUBRICATOR
WORK
ACTUATING CYLINDER

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LESSON PLAN #4

UNIT 2 - POWER SUPPLY

ASSIGNMENT SHEET 1

AFTER READING THE INFORMATION SHEETS (IS2-4-1 AND IS2-4-2) PROVIDED, COMPLETE THE FOLLOWING QUESTIONS IN WRITING OR AS REQUESTED BY YOUR INSTRUCTOR.

1. WHAT ARE THE FUNCTIONS OF THE AIR COMPRESSORS?

2. WHAT IS THE RELIEF VALVE USED FOR?

3. WHAT ARE THE FUNCTIONS OF THE AIR CONDITIONING UNIT?

4. MATCH.

______ A. A CONTROL VALVE AND AN ACTUATOR ALWAYS WORK HAND IN HAND TO POSITION A LOAD.
______ B. A COMPONENT LOCATED IN THE COMPRESSOR INTAKE IN THE PRESSURE LINE.
______ C. A COMPONENT USED TO STOP, START, DIVERT, SHUTTLE, AND MANAGE THE DIRECTION OF THE FLUID (AIR) IN A SYSTEM.
______ D. PUMPS.
______ E. PNEUMATIC SYSTEM IS LIGHTER THAN HYDRAULIC SYSTEMS IN WHAT?

1. FILTER
2. LOAD
3. DIRECTIONAL VALVE
4. ACTUATORS
5. AIR COMPRESSURES

SYLLABUS SHEET FOR LESSON 5
ROBOT SERVICE AND REPAIR

UNIT #2 POWER SUPPLY

ALTERNATING CURRENT POWER

LESSON OBJECTIVE--UPON COMPLETION OF THIS LESSON, THE STUDENT SHOULD BE ABLE TO:

1. VERBALLY EXPLAIN HOW AN ALTERNATING - CURRENT GENERATOR WORKS.
2. VERBALLY DESCRIBE THE CONNECTION OF AN ALTERNATING CURRENT.
3. VERBALLY DESCRIBE THE PRINCIPLE OF AN A.C. MOTOR.
4. LIST THE TYPES OF A.C. MOTORS AND TELL THEIR DIFFERENCES.

TEACHING AIDS:

1.	2-5-H1	SYLLABUS SHEET
2.	T2-5-1	FREQUENCY OF AN ALTERNATING CURRENT
3.	T2-5-2	WYE CONNECTION IN ACTUAL APPLICATION
4.	T2-5-3	A THREE PHASE WYE CONNECTED TO AN ALTERNATING CURRENT
5.	T2-5-4	A DELTA CONNECTION
6.	T2-5-5	A THREE PHASE DELTA CONNECTED TO AN ALTERNATING CURRENT GENERATOR
7.	T2-5-6	THE DIFFERENCE BETWEEN A DELTA AND A WYE CONFIGURATED GENERATOR

INFORMATIONAL ASSIGNMENTS:

1.	IS2-5-1	ALTERNATING CURRENT GENERATOR
2.	IS2-5-2	ALTERNATING CURRENT MOTOR
		ANSWER QUESTIONS FOUND ON ASSIGNMENT SHEETS
1.	AS2-5-1	ALTERNATING CURRENT POWER

REFERENCES:

BEAUCHAMP, W.L. AND MAYFIELD, J.C., BASIC ELECTRICITY, SCOTT, FORESMAN AND COMPANY, 1943.

SELLY, SAMUEL AND POULARIKAS, A.D., ELECTRICAL ENGINEERING, MATRIX PUBLISHERS, INC., OREGON, 1982.

MILLERMASTER, R.A., HARWOOD'S CONTROL OF ELECTRIC MOTORS, WILEY INTERSCIENCE, N.Y. N.Y., 1970.

STEP 1-INTRODUCTION FOR PREPARATION OF THE STUDENT:

MOST ELECTRIC POWER UTILIZED BY HOME, FARM, OR INDUSTRY IS GENERATED BY ALTERNATING CURRENT GENERATORS. THEY ARE ALSO WIDELY USED IN AIRCRAFTS AND AUTOMOBILES. ALTERNATING CURRENT GENERATORS ARE MADE IN MANY DIFFERENT SIZES DEPENDING ON THEIR INTENDED USE.

IN THIS UNIT, THE STUDENT WILL LEARN AND KNOW THE ALTERNATING CURRENT GENERATORS, A.C. MOTORS AND THEIR FUNCTIONS. THE STUDENTS WILL ALSO BE ABLE TO DESCRIBE THEIR PRINCIPLES, FUNCTIONS AND APPLICATIONS.

LESSON SUMMARY AND REVIEW:

1. WHAT ARE THE ESSENTIAL PARTS OF AN ALTERNATING-CURRENT GENERATOR?

2. HOW DO YOU COUNT THE FREQUENCY OF AN ALTERNATING CURRENT?

3. LIST TWO TYPES OF CONNECTIONS OF AN A.C. USED IN INDUSTRY TODAY.

4. TELL WHY A.C. MOTORS ARE WIDELY USED TODAY.

5. DESCRIBE WHAT THE LEFT HAND RULE FOR A MOTOR IS.

6. WHAT SHOULD BE TAKEN CARE OF WHEN MOTORS ARE USED?

A.C. GENERATOR

1. CONSTRUCTION.

ONE KIND OF GENERATOR DESIGNED TO FURNISH LARGE AMOUNTS OF ELECTRICAL ENERGY IS CALLED AN ALTERNATING CURRENT GENERATOR. WE OFTEN CALL IT THE A.C. GENERATOR FOR SHORT. IN ONE SENSE, A MAGNETO IS AN ALTERNATING CURRENT GENERATOR, BECAUSE IT PRODUCES AN ALTERNATING CURRENT. HOWEVER, THE TERM ALTERNATING CURRENT GENERATOR IS USUALLY APPLIED TO THE KIND WHOSE MAGNETIC FIELD IS PROVIDED BY ELECTROMAGNETS INSTEAD OF PERMANENT MAGNETS. AS YOU KNOW, ELECTROMAGNETS ARE NOT ONLY STRONGER THAN PERMANENT MAGNETS, BUT THEIR MAGNETISM CAN ALSO BE CONTROLLED.

THE ESSENTIAL PARTS OF AN A.C. GENERATOR ARE: FIELD MAGNETS, ARMATURE, AND COLLECTOR WITH BRUSHES AND SLIP RINGS. THE ELECTROMAGNETS PROVIDING THE MAGNETIC FIELD ARE SUPPLIED BY A DIRECT CURRENT.

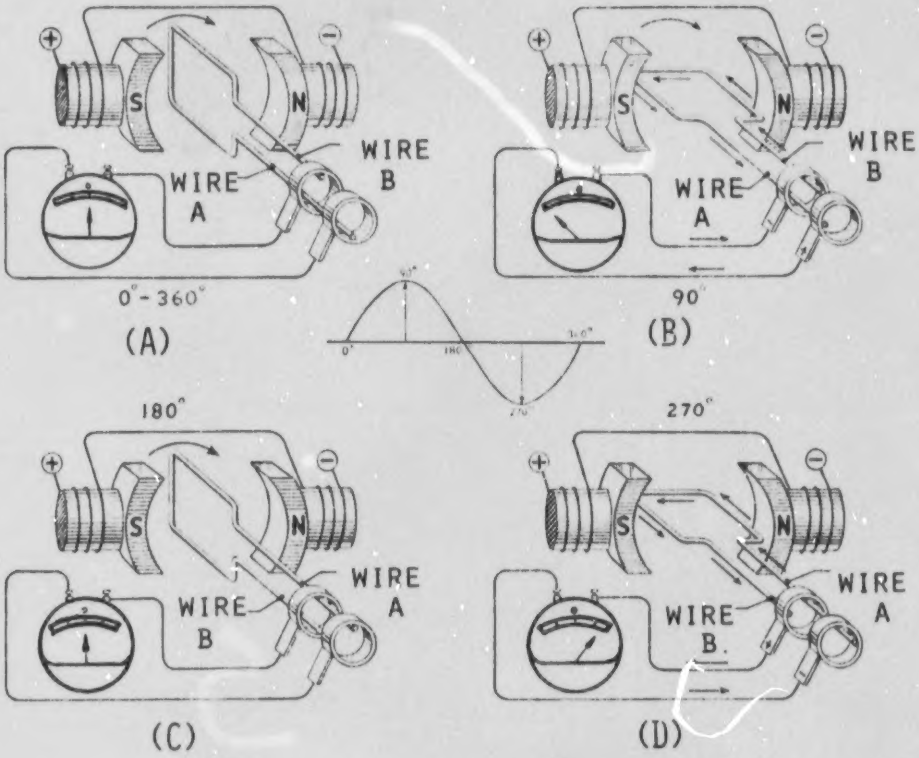
LIKE A MAGNETO, AN A.C. GENERATOR MAY HAVE EITHER A ROTATING ARMATURE AND A STATIONARY FIELD, OR A ROTATING FIELD AND A STATIONARY ARMATURE. FOR REASONS OF ECONOMY AND BETTER CONSTRUCTION, MOST A.C. GENERATORS FURNISHING LARGE AMOUNTS OF ELECTRICAL ENERGY HAVE ROTATING FIELDS AND STATIONARY ARMATURES. WHICHEVER ARRANGEMENT IS USED, BRUSHES AND SLIP RINGS CONNECT THE ROTATING COIL TO THE REST OF THE CIRCUIT.

IF THE FIELD ROTATES, THE COLLECTOR CARRIES DIRECT CURRENT INTO THE FIELD COILS AND BACK AGAIN. IF THE ARMATURE ROTATES, THE COLLECTOR CARRIES ALTERNATING CURRENT INTO THE REST OF THE CIRCUIT AND BACK AGAIN. USUALLY THE FASTER LINES OF FORCE ARE CUT, AND THE GREATER WILL BE THE INDUCED G.M.F.

2. PRINCIPLE.

TO UNDERSTAND HOW AN A.C. GENERATOR WORKS, SEE FIGURE 2-5-1 BELOW.

FIG. 2-5-1
AN ALTERNATING CURRENT IS INDUCED IN A LOOP OF WIRE ROTATING IN A MAGNETIC FIELD.


+
−
S
N
WIRE A
WIRE B
0°-360°
(A)
90°
(B)
0°
90°
180°
270°
360°
180°
270°
WIRE B
WIRE A
(C)
WIRE B.
WIRE A
(D)

(A) THERE IS NO CURRENT FLOW, BECAUSE NO LINES OF FORCE ARE BEING CUT.
(B) A MAXIMUM NUMBER OF LINES OF FORCE ARE BEING CUT, SO MAXIMUM CURRENT FLOWS.
(C) THERE IS NO CURRENT FLOW.
(D) THERE IS MAXIMUM CURRENT FLOW AGAIN BUT IN THE OPPOSITE DIRECTION AS SHOWN BY THE GRAPH IN THE CENTER OF FIG. 2-5-1.

AS MOTION IN FIGURE 2-5-1, IT IS A VERY SIMPLE A.C. GENERATOR, SINCE THEY SHOW ONLY ONE TURN OF WIRE AND NO COIL IN THE ARMATURE. ACTUALLY, A GENERATOR HAS MANY TURNS OF WIRE WOUND AROUND THE IRON CORE OF THE ARMATURE. USUALLY, REGARDLESS OF THE SIZE, ALL GENERATORS OPERATE ON THE SAME BASIC PRINCIPLE--A MAGNETIC FIELD CUTTING THROUGH CONDUCTORS, OR CONDUCTORS PASSING THROUGH A MAGNETIC FIELD. THUS, GENERATORS HAVE AT LEAST TWO DISTINCT SETS OF CONDUCTORS. THEY ARE: 1) A GROUP OF CONDUCTORS IN WHICH THE OUTPUT VOLTAGE IS GENERATED AND 2) A SECOND GROUP OF CONDUCTORS, THROUGH WHICH DIRECT CURRENT IS PASSED TO OBTAIN AN ELECTROMAGNETIC FIELD OF FIXED POLARITY. THE CONDUCTORS IN WHICH THE OUTPUT VOLTAGE IS GENERATED ARE ALWAYS REFERRED TO AS THE ARMATURE WINDINGS. THE CONDUCTORS IN WHICH THE ELECTROMAGNETIC FIELD ORIGINATES ARE ALWAYS REFERRED TO AS THE FIELD WINDINGS.

IN ADDITION TO THE FIELD AND ARMATURE, THERE MUST ALSO BE MOTION BETWEEN THE TWO. TO PROVIDE THIS, A.C. GENERATORS ARE BUILT IN TWO MAJOR ASSEMBLIES: THE STATOR AND THE ROTOR. THE ROTOR ROTATES INSIDE THE STATOR. THE ROTOR MAY BE DRIVEN BY ANY ONE OF A NUMBER OF COMMONLY USED POWER SOURCES, SUCH AS STEAM OR WATER DRIVEN TURBINES, INTERNAL-COMBUSTION ENGINES, AND EVEN LARGE ELECTRIC MOTORS.

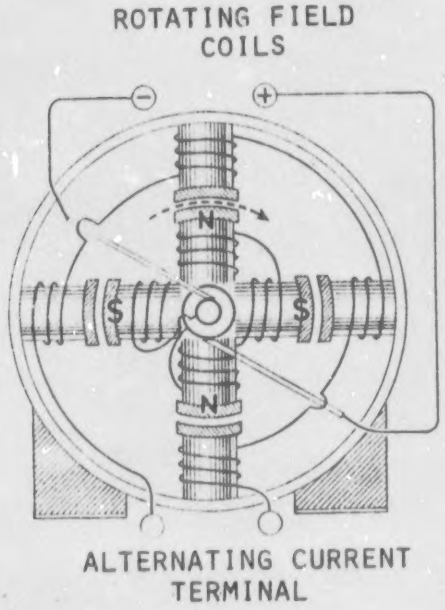
3. OPERATION.

THERE ARE TWO BASIC TYPES OF ALTERNATING CURRENT GENERATORS IN USE TODAY: THE REVOLVING ARMATURE TYPE AND THE REVOLVING FIELD TYPE. HOWEVER, THEY BOTH PERFORM THE SAME BASIC FUNCTION.

IN THE REVOLVING ARMATURE A.C. GENERATOR, THE STATOR PROVIDES A STATIONARY ELECTROMAGNETIC FIELD. THE ROTOR, ACTING AS THE ARMATURE, REVOLVES IN THE FIELD, CUTTING THE LINES OF FORCE, PRODUCING THE DESIRED OUTPUT VOLTAGE. IN THIS GENERATOR, THE ARMATURE OUTPUT IS TAKEN THROUGH THE SLIP RING AND THUS RETAINS ITS ALTERNATING CHARACTERISTICS. FOR A NUMBER OF REASONS, THE REVOLVING ARMATURE A.C. GENERATOR IS SELDOM USED.

THE REVOLVING FIELD A.C. GENERATOR IS THE MOSTLY USED TYPE. IN THIS TYPE OF GENERATOR, DIRECT CURRENT FROM A SEPARATE SOURCE IS PASSED THROUGH THE WINDINGS OF THE ROTOR BY MEANS OF SLIP RINGS AND BRUSHES. THIS ACTION PRODUCES A ROTATING ELECTROMAGNETIC FIELD OF FIXED POLARITY. THE ROTATING MAGNETIC FIELD, FOLLOWING THE ROTOR, EXTENDS OUTWARD AND CUTS THROUGH THE ARMATURE WINDINGS IMBEDDED IN THE SURROUNDING STATOR. AS THE ROTOR TURNS, ALTERNATING VOLTAGES ARE INDUCED IN THE WINDINGS SINCE MAGNETIC FIELDS OF ONE POLARITY AND THE OTHER CUT THROUGH THEM. SINCE THE OUTPUT POWER IS TAKEN FROM STATIONARY WINDINGS, THE OUTPUT MAY BE CONNECTED THROUGH FIXED TERMINALS. THIS IS THE ADVANTAGE YOU GET WHEN THERE IS NO SLIDE CONTACT, AND THE WHOLE OUTPUT CIRCUIT IS ISOLATED THUS MINIMIZING THE DANGER OF AN ARC-OVER. THE WHOLE CONSTRUCTION AND ITS OPERATION IS AS SHOWN IN FIGURE 2-5-2.

FIG. 2-5-2
A ROTATING FIELD AND A STATIONARY ARMATURE. THE FIELD COILS RECEIVE DIRECT CURRENT BY MEANS OF THE BRUSHES AND SLIP RINGS.



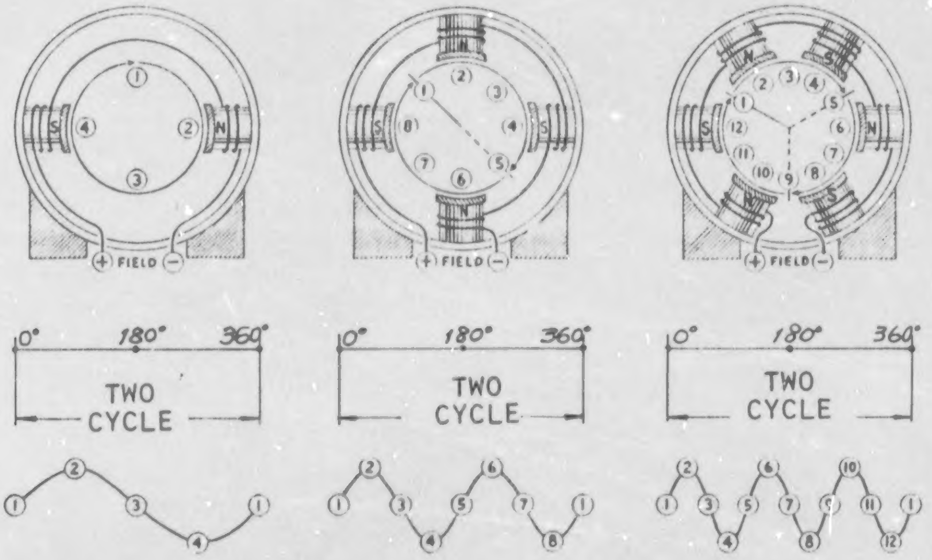
4. PHASE OF AN ALTERNATING CURRENT.

ANY POINTIN A CURVING LINE, SUCH AS THAT USED TO REPRESENT AN ALTERNATING CURRENT, IS CALLED A PHASE. AN A.C. GENERATOR WITH A BI-POLAR ARMATURE IS CALLED A SINGLE PHASE GENERATOR, BECAUSE EACH POINT ON THE CURVING LINE IS THE SAME FOR EVERY CYCLE. A.C. GENERATORS MAY HAVE MULTI-POLAR ARMATURES AND THUS SEVERAL SETS OF ARMATURE COILS PROVIDE ADDITIONAL CIRCUITS FOR INDUCED CURRENTS. THE RESULT IS SEVERAL CURRENTS CHANGING DIRECT AT DIFFERENT TIMES. GENERATORS SUPPLYING SUCH CURRENTS ARE SAID TO BE POLY-PHASE GENERATORS. IF TWO DIFFERENT CURRENTS ARE SUPPLIED, THE GENERATOR IS TWO PHASED. A THREE PHASE GENERATOR SUPPLIES THREE DIFFERENT CURRENTS.

5. FREQUENCY OF AN ALTERNATING CURRENT.

THE FREQUENCY OF AN ALTERNATING CURRENT SUPPLIED BY A GENERATOR IS EQUAL TO THE NUMBER OF PAIRS OF FIELD POLES MULTIPLIED BY THE NUMBER OF ROTATIONS PER SECOND. AS SHOWN IN FIGURE 2-5-3, A SINGLE PAIR OF FIELD POLES PRODUCES TWO ALTERNATIONS FOR EACH COMPLETE ROTATION. THUS, WITH A SINGLE PAIR OF FIELD POLES, A COMPLETE CYCLE OCCURS ONCE IN EACH ROTATION. A CONDUCTOR IN FIELDS OF FOUR AND SIX POLES WILL PRODUCE TWO AND THREE CYCLES RESPECTIVELY.

FIG. 2-5-3
FREQUENCY OF AN A.C.



FOR MORE PURPOSES THE STANDARD 60-CYCLE ALTERNATING CURRENT IS USED. THE FLICKERING IN LIGHT BULBS PRODUCED BY FREQUENCIES LESS THAN 60-CYCLES PER SECOND CAUSES EYE-STRAIN. IN ORDER TO PRODUCE 60-CYCLE CURRENT, A BIPOLAR GENERATOR MUST ROTATE 60 TIMES PER SECOND, OR 3600 TIMES EACH MINUTE (THE SPEED OF A ROTATING PART OF A MACHINE IS USUALLY INDICATED AS REVOLUTION PER MINUTE, OR R.P.M.). A SPEED OF 3600 R.P.M. IS VERY HIGH! IF THE SHAFT OF A GENERATOR TURNS AT THIS SPEED, SPECIAL CONSTRUCTION MUST BE USED FOR THE COIL. IN ADDITION TO THIS, OTHER ENGINEERING PROBLEMS ARE ENCOUNTERED. TO AVOID SUCH A HIGH SPEED AND ALSO TO INCREASE THE AVERAGE STRENGTH OF THE INDUCED E.M.F., ENGINEERS HAVE DESIGNED MULTIPOLAR GENERATORS, WHICH HAVE SEVERAL PAIRS OF POLES IN THE FIELD AND ALSO IN THE ARMATURE. FIGURE 2-5-4 SHOWS HOW USING SEVERAL PAIRS OF FIELD POLES FILL MORE OF THE SPACE IN A GENERATOR WITH MAGNETIC FIELDS WHOSE LINES OF FORCE CAN BE CUT BY THE TURNS OF THE ARMATURE COILS. AS YOU KNOW, CUTTING MORE LINES OF FORCE PER SECOND INCREASES THE INDUCED E.M.F.

USING MORE PAIRS OF FIELD POLES ALSO MAKES IT POSSIBLE TO RUN THE GENERATOR AT SLOWER SPEEDS. FOR EXAMPLE, IF AN A.C. GENERATOR HAS SIX PAIRS OF FIELD POLES, EACH ROTATION PRODUCES SIX CYCLES OF ALTERNATING CURRENT. IN ORDER TO PRODUCE 60-CYCLE ALTERNATING CURRENT, ONLY 10 ROTATIONS PER SECOND ARE ENOUGH. THUS, IF THE NUMBER OF PAIRS OF POLES WERE INCREASED, THE OUTPUT FREQUENCY WOULD ALSO INCREASE WITH NO INCREASE IN SPEED OF ROTATION REQUIRED. THIS IS SHOWN IN THE FOLLOWING FORMULA:

$$F = SP/60$$

WHERE F = FREQUENCY, Hz
S = SPEED OF GENERATOR, RPM
P = NUMBER OF PAIRS OF POLES
60 = CONVERSION FACTOR (F IN Hz AND S IN RPM)

6. CONNECTION OF AN ALTERNATING CURRENT.

THERE ARE TWO TYPES OF CONNECTIONS USED WIDELY IN INDUSTRY TODAY: THE WYE CONNECTION AND THE DELTA CONNECTION.

THE WYE CONNECTION IS USED IN THE THREE PHASE GENERATOR. IN A THREE PHASE GENERATOR RATHER THAN HAVING SIX LEADS COME OUT, ONE OF THE LEADS FROM EACH PHASE MAY BE CONNECTED TO FORM A COMMON JUNCTION. THE STATOR IS THEN CALLED A WYE, AS SHOWN IN FIGURE 2-5-4. IN ACTUALITY, THE COMMON LEAD MAY OR MAY NOT BE BROUGHT OUT OF THE GENERATOR. IF IT IS BROUGHT OUT, IT IS CALLED THE NEUTRAL.

IN ACTUAL APPLICATION EACH LOAD IS CONNECTED ACROSS TWO PHASES IN SERIES, AS SHOWN IN FIGURE 2-5-5. THERE,

R_{AB} = PHASE A IS CONNECTED ACROSS PHASE B IN A SERIES.
R_{AC} = PHASE A IS CONNECTED ACROSS PHASE C IN A SERIES.
R_{BC} = PHASE B IS CONNECTED ACROSS PHASE C IN A SERIES.

CONSEQUENTLY, THE VOLTAGE ACROSS EACH LOAD IS LARGER THAN THE VOLTAGE ACROSS A SINGLE PHASE. A THREE PHASE WYE CONNECTED A.C. GENERATOR SUPPLYING THREE SEPARATE LOADS IS SHOWN IN FIGURE 2-5-6. WHEN UNBALANCED LOADS ARE BEING SUPPLIED, A NEUTRAL MAY BE ADDED. THE NEUTRAL WIRE SERVES AS A COMMON RETURN CIRCUIT FOR ALL THREE PHASES AND MAINTAINS A VOLTAGE BALANCE ACROSS THE LOADS. NO CURRENT FLOWS IN THE NEUTRAL WIRE WHEN THE LOADS ARE BALANCED. THIS CONNECTION METHOD IS KNOWN AS A 3-PHASE 4-WIRE CIRCUIT SYSTEM.

THE LINE VOLTAGE IS GREATER THAN THE VOLTAGE OF A SINGLE PHASE IN THE WYE-CONNECTED CIRCUIT BECAUSE THERE ARE TWO PHASES CONNECTED IN A SERIES BETWEEN EACH PAIR OF LINE WIRES AND THEIR VOLTAGE BECAUSE THE PHASE VOLTAGES ARE NOT IN PHASE WITH EACH OTHER. SO, THE WYE CONNECTION IS USED WHERE HIGH VOLTAGE OUTPUTS ARE DESIRED. APPROXIMATELY, THE OUTPUT VOLTAGE IS 1.73 TIMES AS GREAT AS SINGLE PHASE VOLTAGE.

THE OTHER METHOD OF AN A.C. CONNECTION IS THE DELTA CONNECTION. A THREE-PHASE STATOR MAY BE CONNECTED AS SHOWN IN FIGURE 2-5-7. THIS CONFIGURATION IS CALLED THE DELTA CONNECTION. THE THREE JUNCTION POINTS ARE CONNECTED TO THE LINE WIRES LEADING TO THE LOAD.

FIG. 2-5-4
WYE CONNECTION

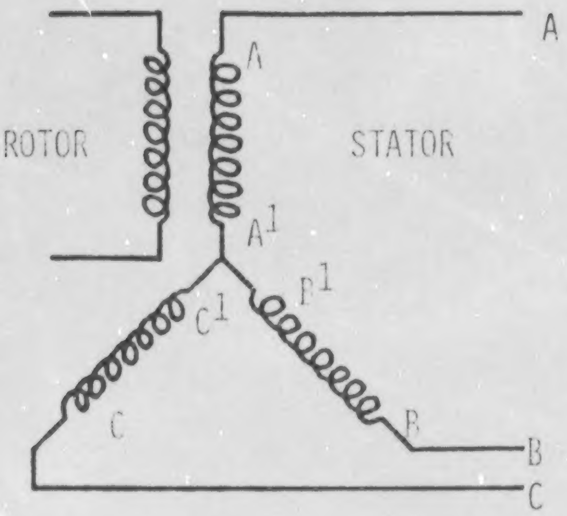

A
A
ROTOR
STATOR
A^1
B^1
C^1
C
B
B
C

FIG. 2-5-5
WYE CONNECTION IN ACTUAL APPLICATION

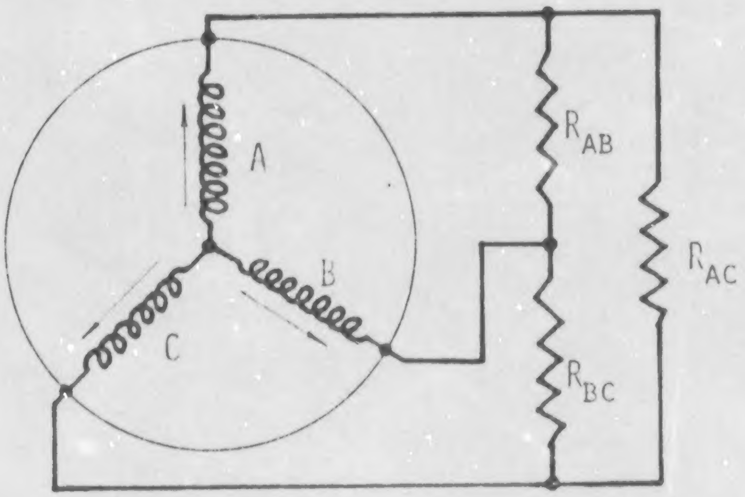

A
B
C
R_{AB}
R_{AC}
R_{BC}

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FIG. 2-5-6
A THREE PHASE WYE CONNECTION

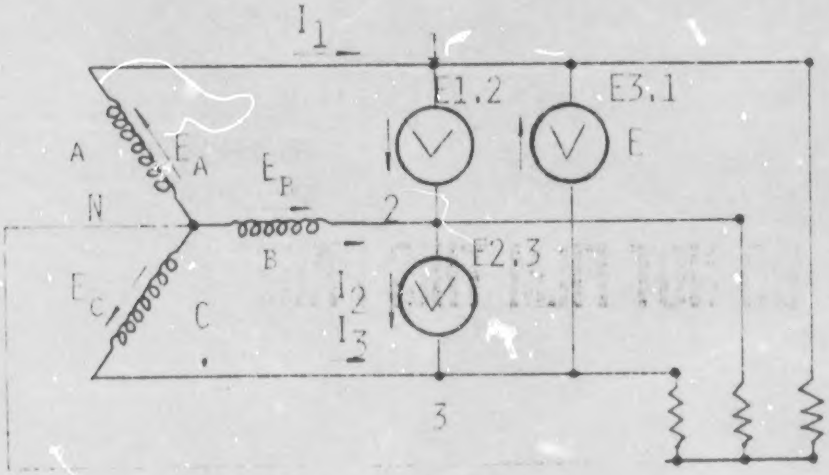
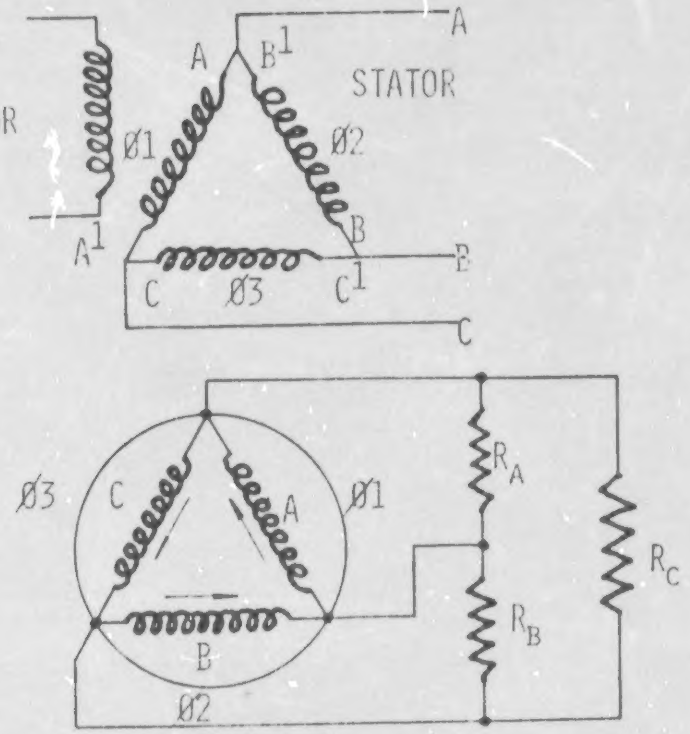

I1
E1.2
E3.1
A
E_A
E_B
E
N
2
B
E2.3
E_C
C
I_2
I_3
3

FIG. 2-5-7
DELTA CONNECTION


A
A
B^1
STATOR
ROTOR
Ø1
Ø2
B
A^1
E
C
Ø3
C^1
C
Ø3
C
A
Ø1
R_A
R_B
R_C
B
Ø2

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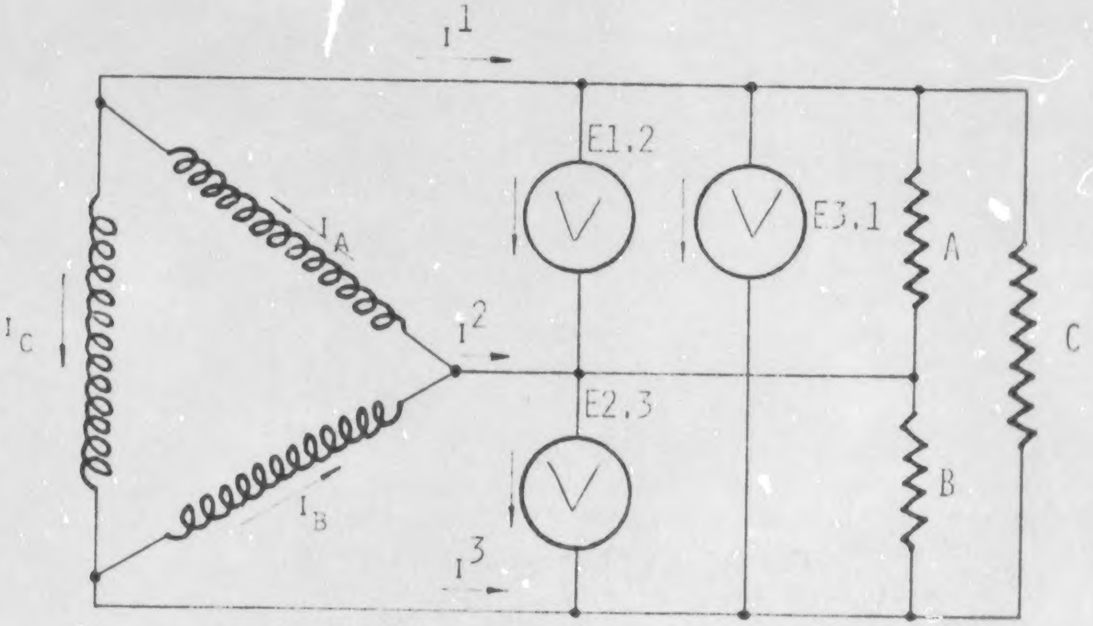
A THREE PHASE DELTA CONNECTED A.C. GENERATOR IS SHOWN IN FIGURE 2-5-8.

FIG. 2-5-8
A THREE PHASE DELTA CONNECTION A.C. GENERATOR



THE GENERATOR IS CONNECTED TO A 3-PHASE CIRCUIT WHICH SUPPLIES A 3-PHASE LOAD. BECAUSE THE LOADS ARE CONNECTED DIRECTLY ACROSS THE PHASES, LINE VOLTAGE IS EQUAL TO PHASE VOLTAGE. WHEN THE GENERATOR PHASES ARE PROPERLY CONNECTED IN DELTA, NO APPRECIABLE CURRENT FLOWS WITHIN THE DELTA LOOP WHEN THERE IS NO EXTERNAL LOAD CONNECTED TO THE GENERATOR. IF ANY ONE OF THE PHASES IS REVERSED WITH RESPECT TO ITS CORRECT CONNECTION, A SHORT-CIRCUIT CURRENT FLOWS WITHIN THE WINDINGS AT NO LOAD, CAUSING DAMAGE TO THE WINDINGS.

IN A DELTA-CONNECTED GENERATOR, THERE IS MORE THAN ONE INTERNAL PATH FOR CURRENT TO FLOW TOWARD THE LOAD. THIS RESULTS IN A HIGHER CURRENT-CARRYING CAPACITY FOR THE GENERATOR. THEREFORE, LINE CURRENT IS GREATER THAN PHASE CURRENT, BUT NOT TWICE AS GREAT BECAUSE THE PHASE CURRENTS ARE NOT IN

PHASE WITH EACH OTHER. LINE CURRENT IS APPROXIMATELY 1.73 TIMES AS GREAT AS A SINGLE-PHASE CURRENT IN A DELTA-CONNECTED GENERATOR.

7. THE MAJOR DIFFERENCE BETWEEN A DELTA AND A WYE CONFIGURATED GENERATOR:

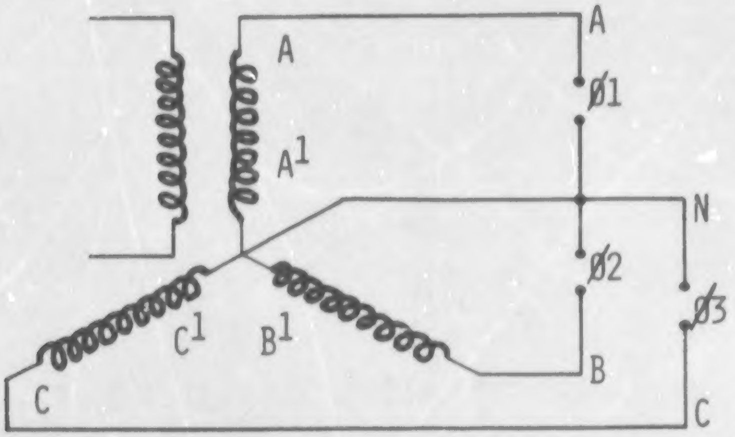
CONFIGURATION	E LINE	I LINE
WYE	1.73 E PHASE	I PHASE
DELTA	E PHASE	3 X I PHASE

8. SINGLE AND THREE-PHASE VOLTAGE OUTPUTS.

WHEN IT IS NECESSARY TO SUPPLY BOTH SINGLE AND THREE-PHASE VOLTAGES FROM A SINGLE THREE-PHASE A.C. GENERATOR, THE WYE CONNECTION IS USED AS SHOWN IN FIGURE 2-5-9.

FIG. 2-5-9

THREE-PHASE WYE-CONNECTED GENERATOR SUPPLYING 3 SINGLE PHASE OUTPUTS



BY CONNECTING THE NEUTRAL LEAD TO THE COMMON JUNCTION IT BECOMES POSSIBLE TO OBTAIN THREE SINGLE-PHASE VOLTAGES AND ONE THREE-PHASE VOLTAGE. FOR EXAMPLE, FROM A GENERATOR DESIGNED TO PRODUCE A 208 VOLT, THREE-PHASE, 60 Hz OUTPUT, IT WOULD BE POSSIBLE TO OBTAIN THREE ADDITIONAL SINGLE-PHASE VOLTAGES OF 120 VOLTS EACH BY USING THE FOUR-WIRE WYE CONNECTION. TO KEEP THIS TYPE OF GENERATOR FROM OVERHEATING, IT IS IMPORTANT THAT THE LOAD BE DISTRIBUTED EVENLY ACROSS THE THREE WINDINGS.

A.C. MOTOR

1. INTRODUCTION.

THE REASON WHY THE A.C. MOTORS ARE USED SO OFTEN IS THAT MOST OF THE POWER GENERATING SYSTEMS PRODUCE ALTERNATING CURRENT. HOWEVER, THERE ARE OTHER ADVANTAGES IN THE USE OF A.C. MOTORS IN ADDITION TO THE WIDE AVAILABILITY OF A.C. POWER. GENERALLY SPEAKING, A.C. MOTORS ARE LESS EXPENSIVE THAN D.C. MOTORS. EVEN THOUGH THE D.C. MOTORS ARE BEST SUITED FOR SOME USES IN THE GREAT MAJORITY OF APPLICATIONS, THE A.C. MOTOR IS BEST.

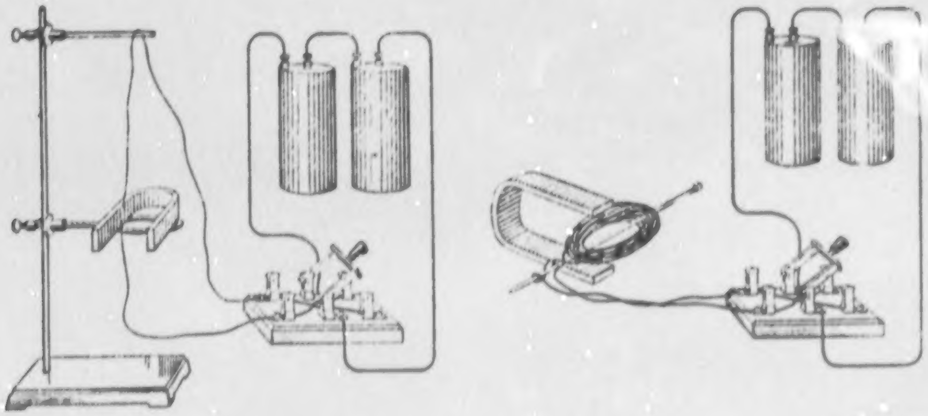
A.C. MOTORS ARE MANUFACTURED IN MANY DIFFERENT SIZES, SHAPES, AND RATINGS FOR USE ON A LARGE NUMBER OF JOBS. THEY ARE WITH EITHER SINGLE OR POLYPHASE SYSTEMS.

SINCE THERE ARE A GREAT NUMBER ON THE SUBJECTS OF A.C. MOTORS IN THIS SECTION, WE ARE JUST DEALING WITH THE MORE COMMON TYPES--THE ROTATING-FIELD INDUCTION MOTOR AND THE SYNCHRONOUS MOTOR.

2. CURRENT-CARRYING CONDUCTOR IN A MAGNETIC FIELD.

AS WE KNOW, THERE ARE SEVERAL DEVICES THAT CHANGE ELECTRICAL ENERGY INTO MECHANICAL ENERGY BY MEANS OF MAGNETISM. WE ALSO KNOW THAT A CURRENT IS INDUCED IN THE WIRE OF A CIRCUIT WHEN THE WIRE IS MOVED ACROSS LINES OF FORCE IN A MAGNETIC FIELD. IN OTHER WORDS, MECHANICAL ENERGY USED IN MOVING THE WIRE OR THE MAGNETIC FIELD IS CHANGED INTO ELECTRICAL ENERGY. AS SHOWN IN FIGURE 2-5-10 (A), A LENGTH OF SMALL INSULATED WIRE IS SUSPENDED BETWEEN THE POLES OF A STRONG U-MAGNET. THE ENDS OF THE WIRE ARE CONNECTED THROUGH A REVERSING SWITCH TO A BATTERY OF TWO DRY CELLS IN A SERIES. THE PURPOSE OF THE SWITCH IS TO PROVIDE AN EASY WAY TO REVERSE THE CURRENT THROUGH THE WIRE. WHEN WE CLOSE THE CIRCUIT BY THROWING THE SWITCH TO ONE SIDE, THE WIRE IS PUSHED OUT OF THE MAGNETIC FIELD IN ONE DIRECTION. NOW, IF WE REVERSE THE CURRENT THROUGH THE WIRE BY THROWING THE SWITCH TO THE OTHER SIDE, THE WIRE IS PUSHED OUT OF THE MAGNETIC FIELD IN THE OPPOSITE DIRECTION.

FIGURE 2-5-10
A CURRENT CARRYING A CONDUCTOR AND A MAGNETIC FIELD



(A) (B)

WE CAN MAKE THE WIRE MOVE FASTER, THAT IS, WITH MORE FORCE, IF WE SEND MORE CURRENT THROUGH THE WIRE BY ADDING CELLS IN A SERIES OR STRENGTHEN THE MAGNETIC FIELD BY ADDING ANOTHER U-MAGNET. FIGURE 2-5-10 (B) IS REPEATED WITH THE WIRE IN A HORIZONTAL POSITION AND THE MAGNET IN A VERTICAL POSITION AND THE WIRE WILL BE PUSHED UPWARD WHEN THE CURRENT FLOWS IN ONE DIRECTION AND DOWNWARD WHEN THE CURRENT FLOWS IN THE OPPOSITE DIRECTION. OF COURSE, THE MOTION OF THE WIRE WILL BE FASTER IF THE ELECTROMAGNET HAS A STRONGER FIELD THAN THE U-MAGNET.

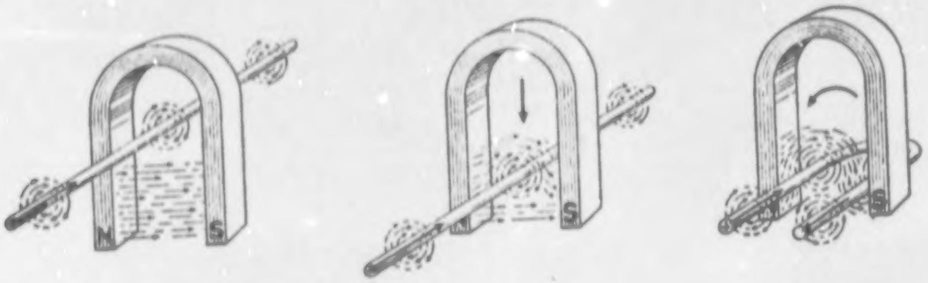
IN FIGURE 2-5-11, DIAGRAM (A) SHOWS THE MAGNETIC FIELD BETWEEN THE POLES OF A U-MAGNET, WHILE ABOVE IT IS SHOWN THE MAGNETIC FIELD AROUND A WIRE CARRYING A CURRENT. DIAGRAM (B) SHOWS WHAT HAPPENS WHEN THE WIRE IS PLACED BETWEEN THE POLES OF THE U-MAGNET. YOU CAN SEE THAT THE LINES OF FORCE OF THE MAGNET AND OF THE WIRE FLOW IN THE SAME DIRECTION ABOVE THE WIRE. THE RESULT IS AN INCREASE IN THE LINES, OR A STRENGTHENING OF THE FLUX ABOVE THE WIRE. HOWEVER, THE LINES

OF FORCE OF THE MAGNET AND OF THE WIRE FLOW IN OPPOSITE DIRECTIONS BELOW THE WIRE. THE RESULT IS A DECREASE IN THE LINES, OR A WEAKENING OF THE FLUX BELOW THE WIRE. SINCE THE FLUX IS STRONGER ABOVE THE WIRE THAN BELOW THE WIRE, THE WIRE IS FORCED DOWNWARD. YOU REMEMBER THAT LINES OF FORCE ACT SOMEWHAT LIKE STRETCHED RUBBER BANDS: THE GREATER NUMBER OF LINES OF FORCE ABOVE THE WIRE APPEARS TO PUSH DOWNWARD ON THE WIRE AS THE WIRE "STRETCHES" THEM. IF THE DIRECTION OF CURRENT FLOW THROUGH THE WIRE IS REVERSED, THE DIRECTION OF THE MAGNETIC FLUX AROUND THE WIRE REVERSES. AS A RESULT, THE WIRE IS PUSHED UPWARD INSTEAD OF DOWNWARD.

DIAGRAM (C) SHOWS A LOOP OF WIRE BETWEEN THE POLES OF THE U-MAGNET. THE TWO ARROWS REPRESENT CURRENT FLOW IN THE OPPOSITE SIDES OF THE LOOP. SINCE THE CURRENT FLOWS IN ONE DIRECTION THROUGH ONE SIDE AND IN THE OPPOSITE DIRECTION THROUGH THE OTHER SIDE, THE MAGNETIC FLUX AROUND THE WIRE ON ONE SIDE IS CLOCKWISE AND COUNTERCLOCKWISE ON THE OTHER SIDE. THE FLUX OF THE MAGNET IS STRENGTHENED ABOVE ONE WIRE AND WEAKENED ABOVE THE OTHER. AS A RESULT, ONE SIDE IS PUSHED DOWN AS THE OTHER SIDE IS PUSHED UP. THIS WILL MAKE THE COIL TURN PART WAY AROUND AS A CURRENT WAS SENT THROUGH ITS WIRE. FROM THIS DIAGRAM, WE UNDERSTAND THAT A CURRENT-CARRYING CONDUCTOR IN

FIG. 2-5-11

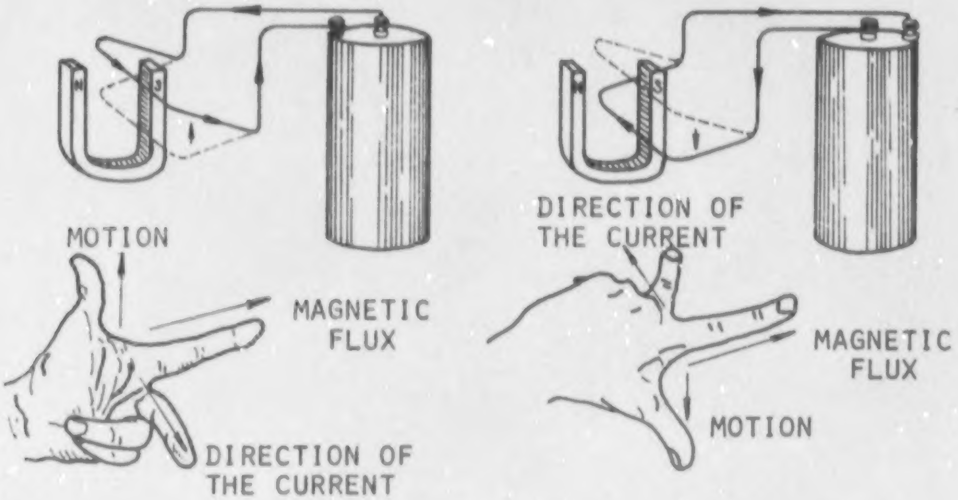
THE MAGNETIC FIELD BETWEEN THE POLES



(A) (B) (C)

A MAGNETIC FIELD TENDS TO MOVE IN A DIRECTION AT RIGHT ANGLES, TO BOTH THE DIRECTION OF THE CURRENT FLOW AND THE DIRECTION OF THE MAGNETIC FLUX. MOTORS ARE OPERATED ON THIS PRINCIPLE; THE ELECTRICAL ENERGY IN THE WIRE IS CHANGED TO MECHANICAL ENERGY BY MEANS OF MAGNETISM. IN FIGURE 2-5-12, THE LEFT-HAND RULE FOR THE MOTOR IS SHOWN. NOTICE THAT THE FORE-FINGER ALWAYS POINTS IN THE DIRECTION OF THE MAGNETIC FLUX-- THAT IS, FROM N TO S,--THE CENTER FINGER ALWAYS POINTS IN THE DIRECTION OF THE CURRENT--THAT IS, FROM POSITIVE TO NEGATIVE; AND THE THUMB ALWAYS POINTS IN THE DIRECTION IN WHICH THE CONDUCTOR MOVES. WHEN ANY TWO OF THESE ELEMENTS ARE KNOWN, THE THIRD CAN BE QUICKLY FOUND.

FIG. 2-5-12
THE LEFT HAND RULE


N
S
MOTION
MAGNETIC FLUX
DIRECTION OF THE CURRENT
N
S
DIRECTION OF THE CURRENT
MAGNETIC FLUX
MOTION

3. INDUCTION MOTOR.

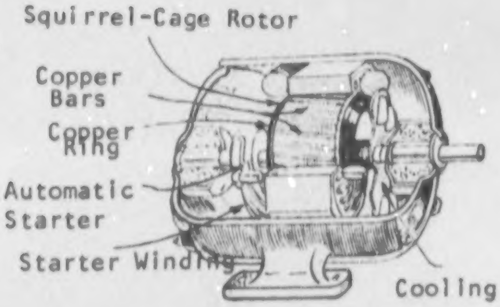
THERE ARE TWO MAIN TYPES OF ALTERNATING CURRENT MOTORS; INDUCTION MOTORS AND SYNCHRONOUS MOTORS. INDUCTION MOTORS IN THEIR SIMPLEST FORM, HAVE TWO PARTS: THE STATIONARY COILS, OR STATORS, AND A ROTATING PART, OR ROTOR.

IN A.C. INDUCTION MOTORS, THE ROTOR CURRENTS ARE SUPPLIED BY ELECTROMAGNETIC INDUCTION. THE STATOR WINDINGS OF AN INDUCTION MOTOR CONTAIN THE OUT-OF-TIME/PHASE CURRENTS, WHICH PRODUCE CORRESPONDING MAGNETOMOTIVE FORCES (M.M F.). THESE MMF'S ESTABLISH A ROTATING MAGNETIC FIELD ACROSS THE AIR GAP, WHOSE SYNCHRONOUS SPEED IS DIRECTLY PROPORTIONAL TO THE FREQUENCY OF THE APPLIED POWER, AND INDEPENDENT OF THE MOTOR LOAD. THE MOTOR DERIVES ITS NAME FROM THE FACT THAT MUTUAL INDUCTION TAKES PLACE BETWEEN THE STATOR AND THE ROTOR UNDER OPERATING CONDITIONS.

THE MAGNETIC REVOLVING FIELD PRODUCED BY THE STATOR CUTS ACROSS THE ROTOR CONDUCTORS INDUCING A VOLTAGE IN THE CONDUCTORS. THIS INDUCED VOLTAGE CAUSES ROTOR CURRENT TO FLOW. HENCE, MOTOR TORQUE IS DEVELOPED BY THE INTERACTION OF THE ROTOR CURRENT AND THE REVOLVING MAGNETIC FIELD, AND THE ROTOR IS NOT CONNECTED ELECTRICALLY TO THE POWER SOURCE.

THE ROTOR OF AN INDUCTION MOTOR IS USUALLY OF THE SQUIRREL-CAGE TYPE, AS SHOWN IN FIGURE 2-5-13. IT CONTAINS AN IRON CORE WITH SLOTS TO HOLD COPPER BARS. THE ENDS OF THE COPPER BARS ARE CONNECTED TO COPPER RINGS. ALTHOUGH THE RINGS ARE NOT CONNECTED TO ANY EXTERNAL CIRCUIT, THEY FORM A CLOSED PATH WITH THE COPPER BARS. THE ROTATING MAGNETIC FIELD INDUCES A LARGE CURRENT IN THE CIRCUIT OF COPPER BARS

FIG. 2-5-13
INDUCTION MOTOR



AND RINGS. THE CURRENT IN THIS CIRCUIT MAGNETIZES THE IRON CORE, WHICH TOGETHER WITH THE COPPER BARS AND RINGS FORMS AN ELECTROMAGNET. THE ROTATING FIELD ACTS ON THE ELECTROMAGNET AND DRAGS IT AROUND. THUS YOU CAN SEE THAT AN INDUCTION MOTOR TURNS SOMEWHAT LIKE THE MAGNETIC SPEEDOMETER OPERATED BY EDDY CURRENTS.

IN AN INDUCTION MOTOR, THE ROTOR DOES NOT MOVE AS FAST AS THE MAGNETIC FIELD. IT MOVES JUST ENOUGH SLOWER THAN THE ROTATING FIELD OF THE STATOR TO ALLOW THE COPPER BARS TO CUT LINES OF FORCE. THE DIFFERENCE BETWEEN THE SPEED OF THE ROTATING FIELD IN THE STATOR AND THE SPEED OF THE ROTOR IS KNOWN AS THE SLIP. AS THE LOAD ON THE MOTOR INCREASES, THE SLIP INCREASES. THE SLIP OF AN INDUCTION MOTOR IS ALSO A MEASURE OF THE LOSSES. IF THE SLIP IS 3½ PER CENT, THAT MUCH OF THE ENERGY IS LOST AS HEAT. INDUCTION MOTORS ARE LIKELY TO GET VERY HOT. THEREFORE, FAN BLADES ARE USUALLY MOUNTED ON THE ROTOR SHAFT TO DRIVE AIR THROUGH THE ROTOR AS THE MOTOR ROTATES.

4. SYNCHRONOUS MOTOR.

THE OTHER TYPE OF ALTNERATING CURRENT MOTOR IS THE SYNCHRONOUS MOTOR. A SYNCHRONOUS MOTOR ROTATES AT A FIXED SPEED, WHICH DEPENDS ON THE FREQUENCY OF THE ALTERNATING CURRENT AND THE NUMBER OF POLES. FOR EXAMPLE, AT 60 CYCLES, A 2-POLE MOTOR WILL REVOLVE 3600 TIMES A MINUTE, WHILE ONE WITH 4 POLES WILL REVOLVE HALF THAT FAST. LARGE SYNCHRONOUS MOTORS ARE MADE VERY MUCH LIKE A.C. GENERATORS, WITH A ROTATING FIELD IN A STATIONARY ARMATURE. IN FACT, ALMOST ANY A.C. GENERATOR CAN BE USED AS A SYNCHRONOUS MOTOR IF SOME WAY OF STARTING IT IS PROVIDED. ONCE THE ROTATING FIELD COILS ARE IN STEP WITH THE ALTERNATIONS OF THE CURRENT SUPPLY, A SYNCHRONOUS MOTOR WILL CONTINUE TO RUN AT A CONSTANT SPEED AS LONG AS THE FREQUENCY OF THE CURRENT SUPPLY DOES NOT CHANGE. USUALLY, THE SYNCHRONOUS MOTORS ARE USED WHERE CONSTANT SPEED WITH A VARYING LOAD IS REQUIRED. THIS IS POSSIBLE SINCE THE SYNCHRONOUS MOTOR HAS THE CAPABILITY OF "LOCKING THE MOTOR IN STEP WITH THE ROTATING MAGNETIC FIELD, ONCE THE ROTOR HAS BEEN BROUGHT UP TO NEAR SYNCHORONOUS SPEED AND THE D.C. FIELD ENERGIZED.

5. SINGLE-PHASE MOTORS.

SINGLE-PHASE MOTORS ARE USED EXTENSIVELY IN COMMERCIAL AND INDUSTRIAL APPLICAITONS REQUIRING LESS THAN A 5 HORSE-POWER MOTOR. THE ADVANTAGES OF USING SINGLE-PHASE MOTORS IN SMALL SIZES ARE THAT THEY ARE LESS EXPENSIVE TO MANUFACTURE THAN OTHER TYPES, AND THEY ELIMINATE THE NEED FOR 3-PHASE A.C. POWER.

SINGLE-PHASE MOTORS ARE USED PRIMARILY IN THE HOME TO OPERATE REFRIGERATORS, WASHING MACHINES, DRYERS, ETC. THEY ARE ALSO USED IN INDUSTRY FOR LIGHT TASKS SUCH AS OPERATING GRINDERS, FANS, PORTABLE TOOLS, AND IN SMALL MACHINE APPLICATIONS.

6. CARE OF MOTORS.

   1. LUBRICATE CORRECTLY.
   2. NEVER PUT OIL ON THE COMMUTATOR OR SLIP RINGS--SINCE A FILM OF OIL PREVENTS A GOOD CONTACT WITH THE BRUSHES.
   3. MUST BE KEPT CLEAN.

SYLLABUS SHEET FOR LESSON 6
ROBOT SERVICE AND REPAIR

UNIT #2 POWER SUPPLY

DC POWER

LESSON OBJECTIVE--UPON COMPLETION OF THIS LESSON, THE STUDENT SHOULD BE ABLE TO:

1. VERBALLY DESCRIBE THE TYPES, CONSTRUCTIONS, AND FUNCTIONS OF THE BATTERIES.
2. VERBALLY EXPLAIN WHAT A DC GENERATOR IS AND TELL WHY IT IS REQUIRED.
3. VERBALLY DESCRIBE THE DC MOTOR, THE DC BRUSHLESS MOTOR, THE STEPPING MOTOR, AND THEIR USAGES.

TEACHING AIDS:

1-6-H1	SYLLABUS SHEET
T2-6-1	THE EFFECTS OF ELECTRODE SIZE AND SEPARATION ON A SIMPLE CELL
T2-6-2	CELL CONNECTION
T2-6-3	CHARGE RETAINTION
T2-6-4	TYPES OF DC MOTORS

INFORMATIONAL ASSIGNMENTS:

IS2-6-1	BATTERIES
IS2-6-2	THE DC GENERATORS
IS2-6-3	THE DC MOTORS
	ANSWER QUESTIONS FOUND ON ASSIGNMENT SHEET
AS2-6-1	DC POWER

REFERENCES:

1. BEAUCHAMP, W.L. AND MAYFIELD, J.C., BASIC ELECTRICITY, SCOTT, FORSMAN AND COMPANY, 1943.
2. MILLERMASTER, RALPH A., HARWOOD'S CONTROL OF ELECTRIC MOTORS, WILEY INTERSCIENCE, NEW YORK, 1970.
3. SAFFORD, E.L., THE COMPLETE HANDBOOK OF ROBOTICS, TAB BOOKS, 1978.

STEP 1--INTRODUCTION FOR PREPARATION OF THE STUDENT:

MANY FUTURISTIC ROBOTIC APPLICATIONS WILL DICTATE THAT A ROBOT WILL HAVE A GREATER DEGREE OF FREEDOM OF MOVEMENT: THUS, THEY WILL DEMAND A POWER SOURCE THAT IS PORTABLE, RELIABLE, AND RENEWABLE. IN ORDER TO MEET THIS NEED, IT CAN BE ACHIEVED THROUGH THE USE OF RECHARGEABLE BATTERIES AND SMALL, POWERFUL, EASILY-CONTROLLED DC MOTORS.

IN THIS UNIT, THE STUDENT WILL LEARN AND KNOW THE BATTERIES THAT COULD POSSIBLY BE USED TO PROVIDE A REUSABLE POWER SOURCE, A DC MOTOR, AND HOW THEY WORK FOR A ROBOT.

LESSON SUMMARY AND REVIEW:

1. WHAT IS A CELL?

2. LIST THREE TYPES OF CELL CONNECTIONS.

3. WHAT ARE THE FEATURES OF NICKEL-CADMIUM BATTERIES?

4. LIST FIVE CHARGE METHODS OF THE BATTERIES.

5. WHY IS A DC GENERATOR NEEDED?

6. LIST THREE THINGS THAT THE MECHANICAL ENERGY SUPPLIED BY A MOTOR DEPENDS UPON

7. WHAT ARE THE FACTORS OF SELECTING A DC MOTOR FOR A GIVEN APPLICATION?

I. BATTERIES

A. TERMS OF BATTERIES

1. CELL: A CELL CONSISTS OF TWO DIFFERENT ELECTRODES IN AN ELECTROLYTE, AS SHOWN IN FIG. 2-6-1.
2. ELECTRODE: EITHER OF THE TWO PLATES OR TERMINALS OF AN ELECTRICAL CELL, BATTERY OR OTHER SOURCES OF ELECTRICAL ENERGY.
3. ELECTROLYTE: A SOLUTION OF A CHEMICAL COMPOUND THAT WILL CONDUCT AN ELECTRIC CURRENT. THE ELECTROLYTE IN A CELL MUST HAVE A CHEMICAL ACTION WITH ONE OF THE ELECTRODES. IT MAY BE A SOLUTION OF AN ACID, A BASE, OR A SALT.

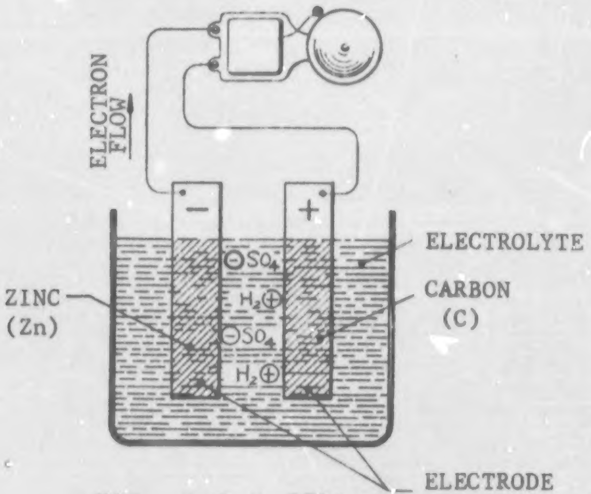


FIG. 2-6-1 CELL

4. PRIMARY CELL: AN ELECTRICAL CELL, SUCH AS A SIMPLE CELL OR DRY CELL, THAT CANNOT BE RECHARGED AFTER ALL ITS STORED CHEMICAL ENERGY HAS BEEN CHANGED TO ELECTRICAL ENERGY.
5. SECONDARY CELL: AN ELECTRICAL CELL, SUCH AS A STORAGE CELL, THAT CAN BE RECHARGED BY SENDING A CURRENT THROUGH THE CELL AND THUS CHANGING ELECTRICAL ENERGY INTO CHEMICAL ENERGY, WHICH IS STORED IN THE CELL TO BE CHANGED BACK TO ELECTRICAL ENERGY AS NEEDED.

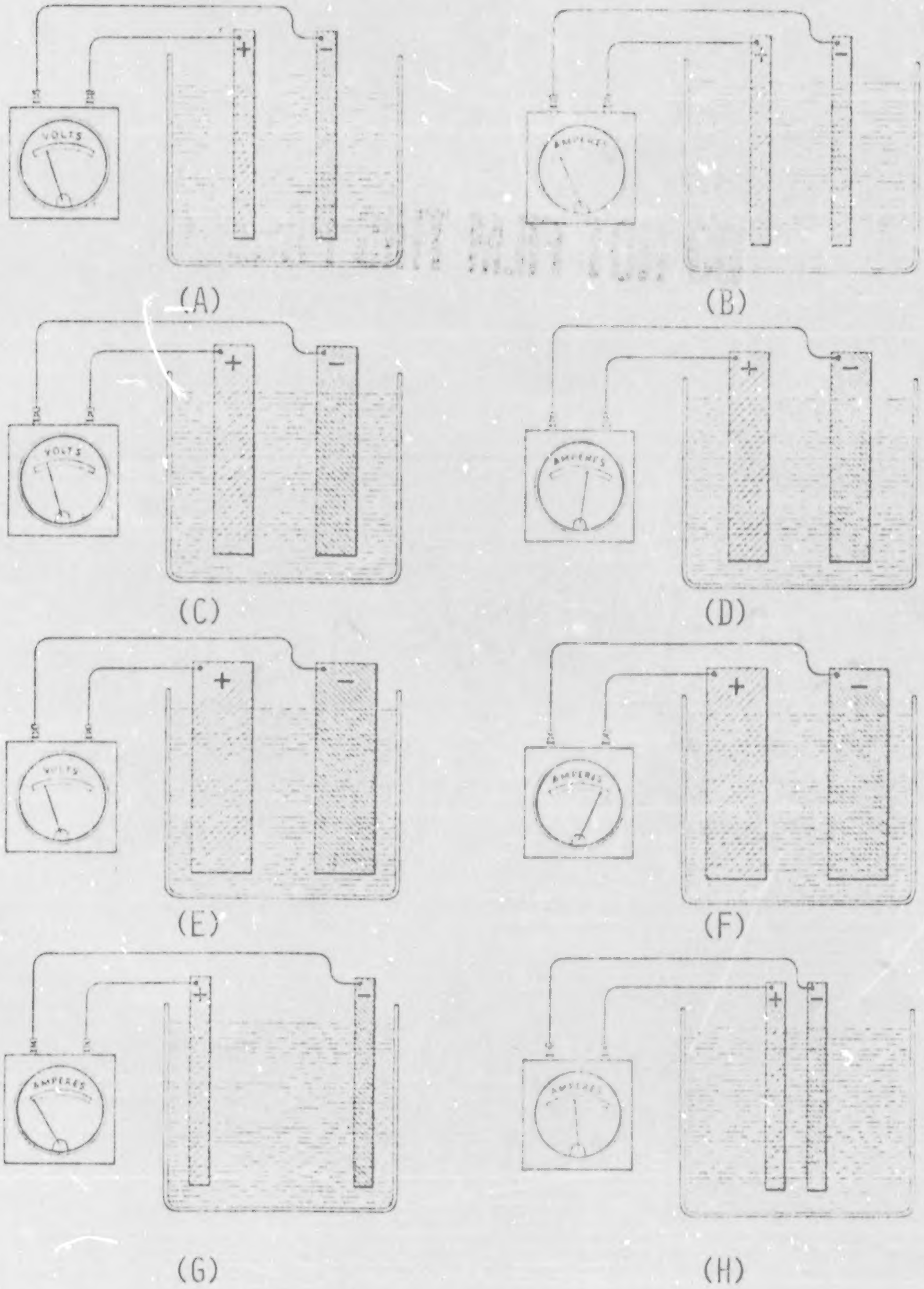

VOLTS
+
−
(A)
AMPERES
+
−
(B)
VOLTS
+
−
(C)
AMPERES
+
−
(D)
VOLTS
+
−
(E)
AMPERES
+
−
(F)
AMPERES
+
−
(G)
AMPERES
+
−
(H)

FIG. 2-6-2
THE EFFECT OF ELECTRODE SIZE AND SEPARATION ON A SIMPLE CELL

B. THE SIMPLE CELL: A CELL IS A DEVICE THAT TRANSFORMS CHEMICAL ENERGY INTO ELECTRICAL ENERGY. THE SIMPLEST CELL, THE VOLTAIC CELL, SHOWN IN FIG. 2-6-1, CONSISTS OF A PIECE OF CARBON (C) AND A PIECE OF ZINC (ZN) SUSPENDED IN A JAR THAT CONTAINS A SOLUTION OF WATER (H_2O) AND SULFURIC ACID (H_2SO_4).

THE CELL IS THE FUNDAMENTAL UNIT OF THE BATTERY. A SIMPLE CELL CONSISTS OF 2 ELECTRODES PLACED IN A CONTAINER THAT HOLDS THE ELECTROLYTE.

C. THE EFFECT OF ELECTRODE SIZE AND SEPARATION:

SHOWN IN FIG. 2-6-2, IS THE EFFECT OF ELECTRODE SIZE AND SEPARATION ON THE VOLTAGE AND AMPERAGE OF A SIMPLE CELL. DIAGRAMS (A), (C), AND (E) SHOW THAT THE VOLTAGE DOES NOT CHANGE AS THE ELECTRODES ARE INCREASED IN SIZE. DIAGRAMS (B), (D), AND (F) SHOW THAT THE AMPERAGE INCREASES AS THE ELECTRODES ARE INCREASED IN SIZE, WHILE DIAGRAMS (G) AND (H) SHOW THAT THE AMPERAGE INCREASES AS THE DISTANCE BETWEEN THE ELECTRODES IS INCREASED.

D. THE DRY CELL: USUALLY A SIMPLE CELL WILL PRODUCE AN E.M.F. AND THUS A CURRENT IN A CIRCUIT; IT WILL NOT PROVIDE ELECTRICAL ENERGY IN LARGE AMOUNTS. COMPARED WITH A WET CELL, A DRY CELL IS FAIRLY CONVENIENT TO CARRY, BECAUSE IT CONTAINS NO LIQUID THAT SPILLS OUT WHEN THE CELL IS TIPPED OVER. SHOWN IN FIG. 2-6-3, IS A CUT VIEW OF A DRY CELL. YOU CAN SEE THAT THE CENTER POST IS CONNECTED TO THE CARBON ROD, WHILE THE OUTSIDE POST IS CONNECTED TO THE ZINC CAN, WHICH HAS A PAPER LINING SOAKED WITH ELECTROLYTE. BETWEEN THIS LINING AND THE CARBON ROD THERE IS A MIXTURE OF CHEMICALS AND SAWDUST. THE LAYERS OF PITCH AND SEALING WILL HELP KEEP THE PASTY MIXTURE FROM DRYING OUT, WHILE AROUND THE CELL IS A CARDBOARD COVER. THE CARBON ROD IS THE POSITIVE ELECTRODE, AND THE ZINC CAN IS THE NEGATIVE ELECTRODE.

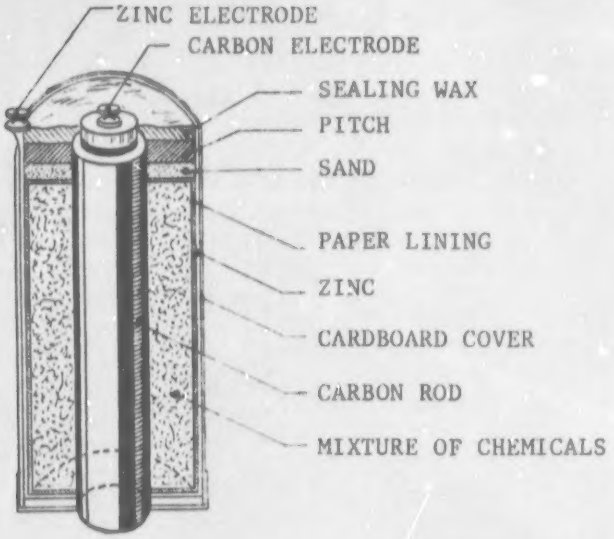

ZINC ELECTRODE
CARBON ELECTRODE
SEALING WAX
PITCH
SAND
PAPER LINING
ZINC
CARDBOARD COVER
CARBON ROD
MIXTURE OF CHEMICALS

FIG. 2-6-3 THE DRY CELL

E. CELL CONNECTION: AS WE KNOW, ALL ORDINARY DRY CELLS SUPPLY CURRENT AT A PRESSURE OF ABOUT 1.5 VOLTS, NO MATTER WHAT THEIR SIZE OR SHAPE IS. BUT MANY TIMES WE NEED MORE PRESSURE THAN A SINGLE CELL WILL PROVIDE IN ORDER TO DRIVE ENOUGH CURRENT THROUGH A CIRCUIT TO MAKE A DEVICE WORK AS IT SHOULD. DEVICES ARE USUALLY RATED IN VOLTS; THEY ARE DESIGNED TO WORK AT A CERTAIN PRESSURE IN THE CIRCUIT. IN ORDER TO GET THE CELLS USED PROPERLY IN THE CURRENT, THERE ARE THREE METHODS TO CONNECT CELLS TOGETHER IN THE CIRCUIT: CELLS IN SERIES, CELLS IN PARALLEL AND CELLS IN SERIES-PARALLEL.

1. CELLS IN A SERIES: AS SHOWN IN FIG. 2-6-5, ALL CELLS ARE CONNECTED IN SERIES TO OBTAIN INCREASED VOLTAGE. WHEN CELLS ARE CONNECTED IN SERIES, THE TOTAL VOLTAGE WILL EQUAL THE SUM OF THE VOLTAGE OF THE INDIVIDUAL CELLS.

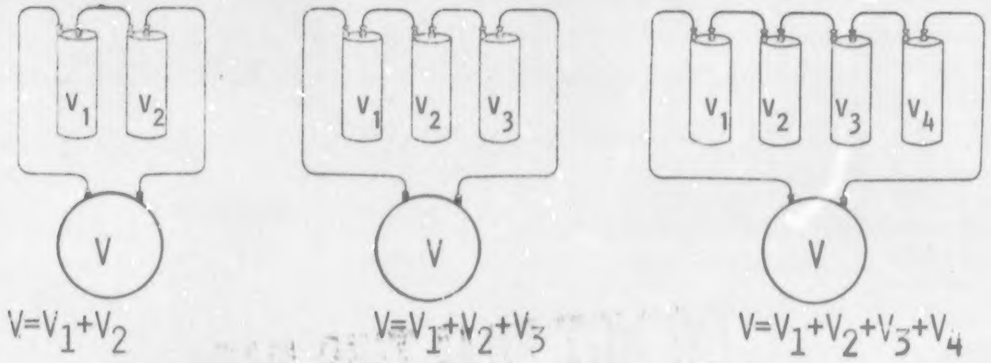


FIG. 2-6-5 CELLS IN SERIES

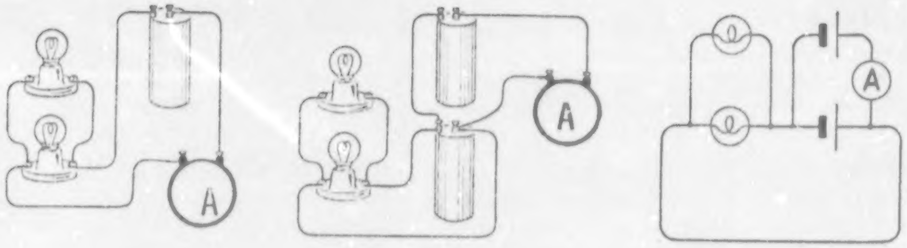


FIG. 2-6-6 CELLS IN PARALLEL

2. CELLS IN PARALLEL: IN ORDER TO PROLONG THE LIFE OF THE DRY CELL WITHOUT USING UP THE INDIVIDUAL CELLS TOO FAST, WE USUALLY CONNECT THE CELLS IN PARALLEL, AS SHOWN IN FIG. 2-6-6.
3. CELL IN SERIES-PARALLEL: IN ORDER TO INCREASE THE VOLTAGE AND CURRENT IN A CIRCUIT AT THE SAME TIME, WE USUALLY USE SERIES-PARALLEL METHOD TO CONNECT TWO OR MORE CELLS TOGETHER. AS SHOWN IN FIG. 2-6-7, IS A METHOD OF CONNECTING CELLS IN A CIRCUIT THAT GROUPS IN SERIES ARE ALSO IN PARALLEL WITH OTHER GROUPS IN SERIES.

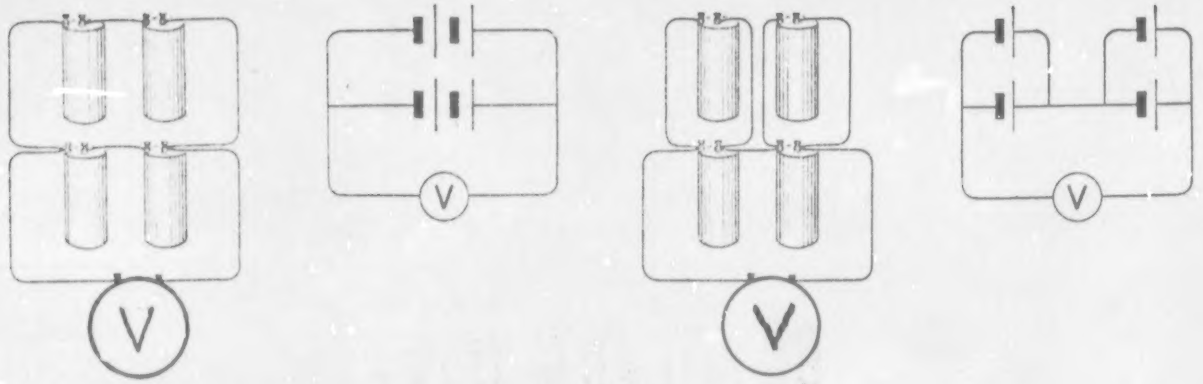


FIG. 2-6-7 CELLS IN SERIES-PARALLEL

F. BATTERIES: BATTERIES ARE WIDELY USED AS SOURCES OF DIRECT-CURRENT ELECTRICAL ENERGY WHEN OTHER SOURCES ARE NOT READYILY AVAILABLE OR FEASIBLE. THERE ARE THREE KINDS OF BATTERIES USED WIDELY IN OUR SOCIETY TODAY. SEE FIG. 2-6-8.

LEAD ACID BATTERY	1. RECHARGEABLE 2. INEXPENSIVE	1. HEAVY 2. PRONE TO LEAKAGE OR SPILLAGE OF THE ELECTROLYTE SOLUTION.
NICKEL-CADMIUM BATTERY	1. RECHARGEABLE 2. FAIRLY LIGHT-WEIGHT 3. LONGER LIFE	1. EXPENSIVE
GELLED-ELECTROLYTE BATTERY	1. HIGH ENERGY 2. LOW INITIAL COST 3. HIGH ENERGY REQUIREMENTS	

FIG. 2-6-8 KINDS OF BATTERIES

SINCE MOST OF US ARE FAMILIAR WITH THE LEAD-ACID BATTERIES USED IN AUTOMOBILES, WE WILL DIRECT OUR STUDIES TO THE MOST COMMON AND RECHARGEABLE NICKEL-CADMIUM AND GELLED-ELECTROLYTE BATTERIES.

G. NICKEL-CADMIUM BATTERIES
  1. FEATURES
    A. MAINTENANCE FREE-SEALED TYPE
    B. MAINTAIN CONSTANT VOLTAGE
    C. HIGH RATES RECHARGEABLE
    D. WIDE TEMPERATURE RANGE--40°F TO 140°F (-40°C TO 60°C)
    E. LONG PERIODS OF TIME IN STORAGE
  2. GENERAL CHARACTERISTICS: SHOWN IN FIG. 2-6-9 IS THE THREE TYPES OF STANDARD NICKEL-CADMIUM CELLS: RECTANGULAR, BUTTON AND CYLINDRICAL. THE CYLINDRICAL TYPE IS THE MOST COMMON AND WIDELY USED CELL. THESE CELLS HAVE SOME COMMON CHARACTERISTICS WHICH ARE AS FOLLOWS:
    A.

CHARGE RETAINTION

ITEM	CELL TYPE	1 MONTH	2 MONTHS	5 MONTHS
1	RECTANGULAR	75%	70%	63%
2	BUTTON	75%	70%	63%
3	CYLINDRICAL	75%	50%	15%

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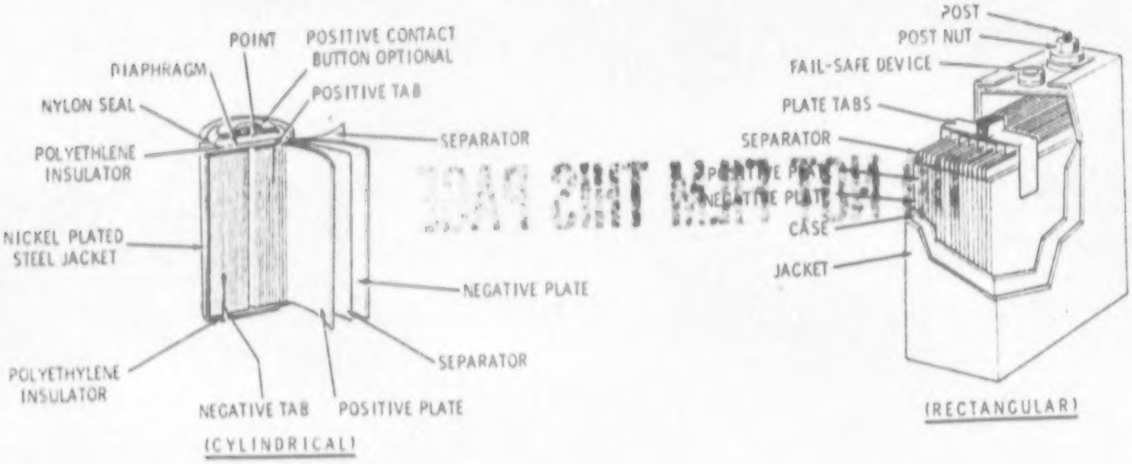

POINT
POSITIVE CONTACT BUTTON OPTIONAL
DIAPHRAGM
POSITIVE TAB
NYLON SEAL
SEPARATOR
POLYETHLENE INSULATOR
NICKEL PLATED STEEL JACKET
NEGATIVE PLATE
SEPARATOR
POLYETHYLENE INSULATOR
NEGATIVE TAB
POSITIVE PLATE
(CYLINDRICAL)
POST
POST NUT
FAIL-SAFE DEVICE
PLATE TABS
SEPARATOR
POSITIVE PLATE
NEGATIVE PLATE
CASE
JACKET
(RECTANGULAR)

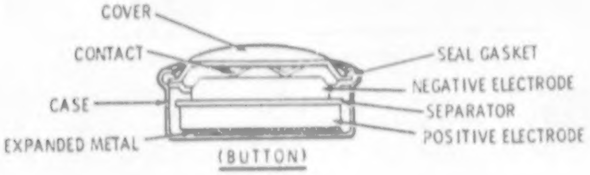

COVER
CONTACT
CASE
EXPANDED METAL
SEAL GASKET
NEGATIVE ELECTRODE
SEPARATOR
POSITIVE ELECTRODE
(BUTTON)

FIG. 2-6-9 THREE STANDARD NICKEL-CADMIUM CELLS

B. CAPACITY: CAPACITY IS THE TERM USED TO DEFINE THE TOTAL AMOUNT OF ELECTRICAL ENERGY THAT CAN BE OBTAINED FROM A FULLY-CHARGED CELL.

THE CAPACITY OF A NICKEL-CADMIUM CELL IS DETERMINED BY THE AMOUNT OF CURRENT THAT CAN BE OBTAINED FROM A FULLY-CHARGED CELL, DISCHARGED AT 68°F (20°C) FOR 5 HOURS TO A 1.0-VOLT CUTOFF. THIS IS REFERRED TO AS THE C/5 RATE.

C. DISCHARGE RATE=THE CURRENT AT WHICH A CELL OR BATTERY IS DISCHARGED. DISCHARGE RATE=AMPERE HOURS/TIME.

3. CHARGING TECHNIQUES

   A. TRICKLE CHARGE: A TRICKLE CHARGE IS GENERALLY APPLIED TO A CELL OR BATTERY WHOSE PRIMARY FUNCTION IS TO PROVIDE AS STANDBY OR EMERGENCY POWER TO ELECTRONIC EQUIPMENT. THE TRICKLE CHARGE RATE IS NOT SUFFICIENT TO EFFICIENTLY CHARGE THE CELL OR BATTERY, AND IT IS USED ONLY AFTER THE CELL OR BATTERY HAS BEEN FULLY CHARGED.

   B. MINIMUM CHARGE: A MINIMUM CHARGE FOR NICKEL-CADMIUM CELLS ARE NORMALLY BETWEEN C/20 AND C/10. THIS CHARGE RATE IS SUFFICIENT TO BRING A CELL UP TO A FULLY CHARGED CONDITION AND TO MAINTAIN IT IN HIS STATE.

   C. STANDARD CHARGE: THE STANDARD OR NORMAL CHARGE FOR A NICKEL-CADMIUM BATTERY IS A 14 HOUR OR OVERNIGHT CHARGE, USING CONSTANT CURRENT, AT THE C/10 RATE.

   D. QUICK CHARGE: FOR OPERATIONS REQUIRING 2 OR 3 FULL CYCLES IN A 24-HOUR PERIOD, QUICK CHARGE NICKEL-CADMIUM CELLS ARE AVAILABLE. THESE CELLS ARE DESIGNED TO ACCEPT AN OVERCHARGE CURRENT UP TO THE C/3 RATE, AND WILL RECHARGE IN 3 TO 5 HOURS, DEPENDING ON THE CHARGE AND THE CELL. CELLS OF THIS TYPE ARE IDEAL FOR EQUIPMENT THAT HAS TO BE USED SEVERAL TIMES DURING A 24-HOUR PERIOD.

   E. RAPID CHARGE: RAPID OR FAST CHARGING IS FOR THOSE APPLICATIONS THAT REQUIRE RECHARGING IN LESS THAN 3 HOURS (GREATER THAN THE C/3 RATE).

4. CHARGING PARAMETERS: SHOWN IN FIG. 2-6-10 IS A TYPICAL CONSTANT-CURRENT BATTERY CHARGER USING HALF WAVE RECERTIFICATION. AS A GUIDE FOR CONSTRUCTING THIS BASIC CHARGING CIRCUIT, COMPONENTS SHOULD BE SELECTED AS FOLLOWS:

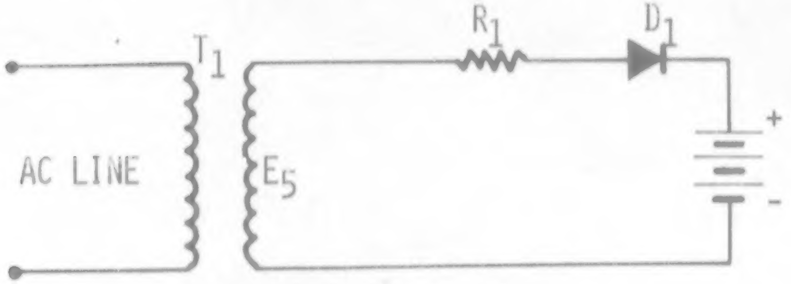


FIG. 2-6-10 BASIC CHARGING CIRCUIT

A. TRANSFORMER (T_1); SECONDARY-VOLTAGE (E_5) SHOULD BE .2 TO 2.5 TIMES THE NOMINAL VOLTAGE OF THE BATTERY OR CELL BEING CHARGED.

B. RECTIFIER (D_1) SHOULD HAVE A PEAK INVERSE VOLTAGE (PIV) OF AT LEAST TWICE THE VOLTAGE OF THE TRANSFORMER SECONDARY WINDING.

C. RESISTOR (R_1) SHOULD HAVE A RATED WATTAGE THAT IS AT LEAST EQUAL TO THE PRODUCT OF THE CHARGING CURRENT AND THE SECONDARY VOLTAGE OF TRANSFORMER T_1.

D. R_1 OHMIC VALUE IS COMPUTED TO REDUCE THE CHARGING CURRENT TO THE SPECIFIED VALUE FOR THE BATTERY.
FOR EXAMPLE: TO CHARGE A 6-VOLT; 2.4 AH BATTERY AT THE C/3 RATE OF 800 MA:
NOMINAL VOLTAGE= 6 VOLTS
TRANFORMER SECONDARY= 2.5x6=15 VOLTS (MIN.)
RECTIFIER PIV= 2x15= 30 VOLTS (MIN.)
RESISTOR WATTAGE= 15x800 MA= 12 WATTS (MIN.)
CHARGE TIME-3.5 TO 4 HOURS AT ROOM TEMPERATURE (MIN.)

5. CARE AND MAINTENANCE

A. MAKE SURE THE BATTERY YOU HAVE CHOSEN WILL MEET YOUR REQUIREMENTS AND CHECK IT FOR FULL CAPACITY.

B. MAKE SURE THEY HAVE A FIRM CONTACT ON CLEAN SURFACES. DO NOT SOLDER DIRECTLY TO THE CELL.

C. NICKEL-CADMIUM CELLS OR BATTERIES SHOULD BE USED IN SERIES; CONNECTING THEM IN PARALLEL IS NOT RECOMMENDED.

D. CONSTANT CURRENT, OR MODIFIED CONSTANT CURRENT CHARGING, IS THE PREFERRED METHOD TO CHARGE NICKEL-CADMIUM BATTERIES.

E. BE CAREFUL TO PREVENT ACCIDENTAL SHORT CIRCUITING WHEN YOU HANDLE NICKEL-CADMIUM BATTERIES.

F. SHOULD BE KEPT COOL TO IMPROVE BATTERY LIFE AND PERFORMANCE.

G. THE GELLED-ELECTROLYTE BATTERY SHOULD BE CHARGED AS SOON AS POSSIBLE AFTER IT IS DISCHARGED AND BEFORE IT IS STORED. LEAVING THE BATTERY IN A DISCHARGED

CONDITION FOR PROLONGED PERIODS CAUSES SULFATION ON THE POSITIVE AND NEGATIVE PLATES. THIS WILL EITHER REDUCE BATTERY CAPACITY OR EVENTUALLY CAUSE BATTERY FAILURE.

H. GELLED-ELECTROLYTE BATTERIES

(1) GENERAL INFORMATION: GELLED-ELECTROLYTES HAVE MANY OF THE SAME FEATURES AS NICKEL-CADMIUM BATTERIES. THEY MAY BE CHARGED AND DISCHARGED FROM 100 UP TO 1000 CYCLES AND RECHARGED IN LESS THAN 14 HOURS.

THE GELLED-ELECTROLYTE BATTERIES REMAIN CHARGEABLE FOR MORE THAN A YEAR WITHOUT BEING USED AND CAN BE STORED FOR MUCH LONGER PERIODS OF TIME WHEN THEY ARE KEPT IN A CHARGED CONDITION.

THE GELLED-ELECTROLYTE BATTERIES HAVE A VERY WIDE OPERATION TEMPERATURE RANGE, DURING DISCHARGE: -40°F TO 140°F; DURING CHARGE: -4°F TO 122°F; CAPACITY IS RATED AT 68°F.

THE GELLED-ELECTROLYTE BATTERIES--UNLIKE SILVER, NICKEL, OR CADMIUM BATTERIES--USE LEAD DIOXIDE, WHICH IS LESS EXPENSIVE TO PRODUCE AND FAR MORE READILY AVAILABLE.

(2) CAPACITY: THE CAPACITY OF A CELL IS EXPRESSED IN AMPERE-HOURS (AH) OR MILLIAMPERE-HOURS (MAH) WHICH IS A CURRENT-TIME PRODUCT. THE CAPACITY VALUE IS DEPENDENT UPON THE DISCHARGE CURRENT, TEMPERATURE DURING DISCHARGE AND THE FINAL CUT-OFF VOLTAGE.

THE CAPACITY OF GELLED-ELECTROLYTE BATTERY IS MEASURED AT THE 20 HOUR RATE, AT 68°F TO A CIRCUIT CUT-OFF VOLTAGE OF 1.75 VOLTS PER CELL. THE NOMINAL OPERATING VOLTAGE IS 1.97 VOLTS PER CELL AT THIS RATE.

THE GELLED-ELECTROLYTE BATTERY IS DISCHARGED AT THE 20 HOUR, 15 HOUR, 5 HOUR AND 1 HOUR RATES. THESE RATES ARE ALSO DESIGNED AS C/20, C/15, C/5 AND C/1 RESPECTIVELY.

(3) CHARGING CONSIDERATIONS

(A) INITIAL CHARGE CURRENT: EACH BATTERY WILL DICTATE A MAXIMUM CURRENT THAT SHOULD NOT BE EXCEEDED DURING CHARGING THE MAXIMUM CHARGING CURRENT FOR THE GELLED-ELECTROLYTE BATTERIES IS RECOMMENDED TO BE NO MORE THAN 3 TO 4 TIMES THE 20-HOUR DISCHARGE CURRENT FOR THAT PARTICULAR BATTERY.

(B) END OF CHARGE CURRENT: FULLY-CHARGED GELLED-ELECTROLYTE BATTERIES ON FLOAT OR MAINTENANCE CHARGE WILL NORMALLY ACCEPT SMALL CHARGING CURRENTS WITHIN A SPECIFIC RANGE. THIS RANGE DEPENDS ON TERMINAL VOLTAGE, TEMPERATURE, AND THE AMPERE-HOUR CAPACITY OF THE BATTERY. AT ROOM TEMPERATURE, A 6-VOLT BATTERY FLOATED AT 7 VOLTS WILL USUALLY ACCEPT CONTINUOUSLY FROM 1 TO 3 MA PER AMPERE-HOUR OF RATED CAPACITY.

(C) TEMPERATURE EFFECTS: IF THE IN-SERVICE BATTERY TEMPERATURE IS GREATLY DIFFERENT FROM ROOM TEMPERATURE, OR IF LARGE TEMPERATURE VARIATIONS ARE ENCOUNTERED DURING OPERATION, THE CHARGING VOLTAGE MUST BE COMPENSATED FOR TEMPERATURE TO REALIZE MAXIMUM BATTERY PERFORMANCE AND LIFE.

II. THE DC GENERATOR

A. INTRODUCTION: FOR SOME PURPOSES, SUCH AS ELECTROLYSIS, ELECTROPLATING, CHARGING STORAGE BATTERIES, AND COMMUNICATION WORK, DIRECT CURRENT IS NEEDED. CELLS OR BATTERIES SUPPLY DIRECT CURRENT, BUT THEY ARE TOO EXPENSIVE TO USE WHEN LARGE CURRENTS MUST BE PROVIDED FOR A CONSIDERABLE LENGTH OF TIME. THEREFORE, A DIRECT CURRENT GENERATOR IS ORDINARILY USED TO SUPPLY LARGE AMOUNTS OF DIRECT CURRENT.

B. DIRECT CURRENT GENERATOR: A GENERATOR THAT SUPPLIES DIRECT CURRENT BY MEANS OF A SWITCHING DEVICE CALLED A COMMUTATOR, WHICH CHANGES INDUCED ALTERNATING CURRENT INTO PULSATING DIRECT CURRENT.

THE PARTS OF A DIRECT CURRENT GENERATOR ARE THE SAME AS THOSE OF AN ALTERNATING CURRENT GENERATOR, WITH ONE EXCEPTION: THE COLLECTOR CONTAINS A DEVICE CALLED A COMMUTATOR INSTEAD OF SLIP RINGS. THE COMMUTATOR IS A SWITCHING DEVICE THAT REVERSES THE FLOW OF CURRENT INDUCED IN THE ARMATURE COIL AT JUST THE RIGHT TIMES TO MAKE A DIRECT CURRENT FLOW THROUGH THE EXTERNAL CIRCUIT. IT IS CALLED A COMMUTATOR BECAUSE IT COMMUTES OR CHANGES THE DIRECTION OF THE CURRENT.

C. PRINCIPLE: LIKE AC GENERATORS, DC GENERATORS USUALLY HAVE ELECTROMAGNETS TO PROVIDE A MAGNETIC FIELD. IN DC GENERATORS, HOWEVER, THEY ALWAYS HAVE ROTATING ARMATURES AND STATIONARY FIELD MAGNETS. IT IS THEORETICALLY POSSIBLE TO MAKE A DC GENERATOR WITH A STATIONARY ARMATURE AND A ROTATING FIELD, BUT FOR ENGINEERING REASONS THIS IS NOT DONE. FOR ONE THING, THE COMMUTATOR MUST BE MOUNTED ON THE SHAFT. SINCE THE COMMUTATOR IS CONNECTED TO THE ARMATURE, IT WOULD BE VERY AWKWARD TO HAVE ONE ROTATE WITHOUT THE OTHER. THE MAIN THING FOR US TO LEARN ABOUT THE OPERATION OF A DIRECT CURRENT GENERATOR IS HOW THE COMMUTATOR IS CONNECTED TO DO ITS WORK. FIG. 2-6-11 SHOWS A COMMUTATOR IN ITS SIMPLEST FORM.

INSTEAD OF A CONTINUOUS BAND LIKE A SLIP RING, IT IS SPLIT INTO TWO PARTS CALLED SEGMENTS OR SECTORS. EACH END OF THE COIL IS CONNECTED TO A SEGMENT, AND ONE BRUSH IS PROVIDED FOR EACH SEGMENT. FROM THIS FIGURE, WE KNOW HOW A COMMUTATOR WORKS DURING ONE ROTATION OF THE COIL.

IN THE FIRST DIAGRAM, THE SIDES OF THE COIL ARE MOVING PARALLEL TO THE LINES OF FORCE. NO LINES OF FORCE ARE CUT, AND NO E.M.F. IS INDUCED. JUST AS IN AN A.C. GENERATOR, NO CURRENT FLOWS. EACH BRUSH TOUCHES BOTH COMMUTATOR SEGMENTS.

IN THE SECOND DIAGRAM, SIDE A OF THE COIL CUTS UPWARD THROUGH THE MAGNETIC FIELD AS SIDE B CUTS DOWNWARD. AN E.M.F. IS INDUCED, AND A CURRENT FLOWS IN THE COIL AND THROUGH THE CIRCUIT. NOTICE THAT AT THIS POINT EACH SEGMENT IS IN CONTACT WITH ONLY ONE BRUSH.

THE THIRD DIAGRAM SHOWS THE SIDES OF THE COIL MOVING PARALLEL TO THE LINES OF FORCE AS IN THE FIRST DIAGRAM. NO E.M.F. IS INDUCED, AND NO CURRENT FLOWS. AGAIN NOTICE THAT EACH BRUSH TOUCHES BOTH COMMUTATOR SEGMENTS.

THE FOURTH DIAGRAM SHOWS SIDE A CUTTING DOWNWARD THORUGH THE MAGNETIC FIELD AS SIDE B CUTS UPWARD. LINES OF FORCE ARE CUT IN THE OPPOSITE DIRECTION BY THE SIDES OF THE COIL. AN E.M.F. IS INDUCED, AND A CURRENT FLOWS BUT IN THE OPPOSITE DIRECTION TO THAT SHOWN IN THE SECOND DIAGRAM. HOWEVER, THE COMMUTATOR SEGMENTS HAVE ROTATED UNTIL EACH ONE TOUCHES THE OTHER BRUSH. CURRENT FLOWS THROUGH THE EXTERNAL CIRCUIT IN THE SAME DIRECTION AS BEFORE.

BY MEANS OF A COMMUTATOR, THE GENERATOR THUS SUPPLIES A DIRECT CURRENT TO THE EXTERNAL CIRCUIT. THE CURVING LINE IN FIG. 2-6-11 SHOWS THAT THE E.M.F. INCREASES FROM ZERO TO A MAXIMUM AND THEN DECREASES TO ZERO, JUST AS IN AN ALTERNATING CURRENT. HOWEVER, INSTEAD OF REVERSING, THE E.M.F. AGAIN INCREASES TO A MAXIMUM AND THEN DECREASES. THE COMMUTATOR KEEPS THE CURRENT IN THE EXTERNAL CIRCUIT FLOWING IN THE SAME DIRECTION. ANOTHER THING TO NOTICE IN THE DIAGRAMS IS THAT WHEN A CURRENT IS INDUCED, THE

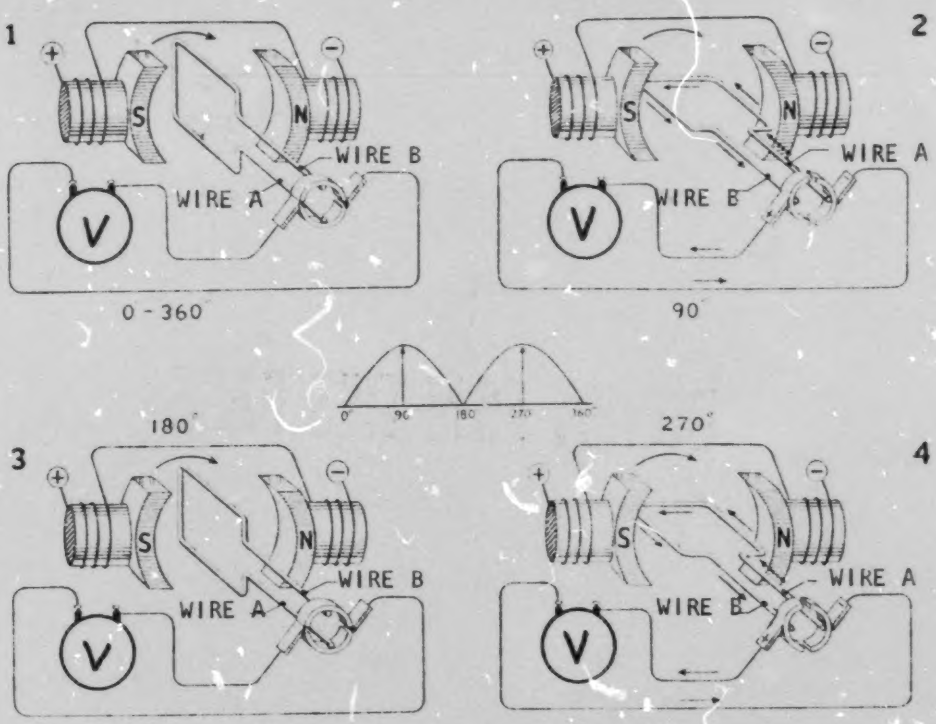

1
+
S
N
−
WIRE B
WIRE A
V
0 - 360°
2
+
S
N
−
WIRE A
WIRE B
V
90°
0°
90
180
270
360
180°
3
+
S
N
−
WIRE B
WIRE A
V
270°
4
+
S
N
−
WIRE A
WIRE B
V

FIG. 2-6-11 DC GENERATOR

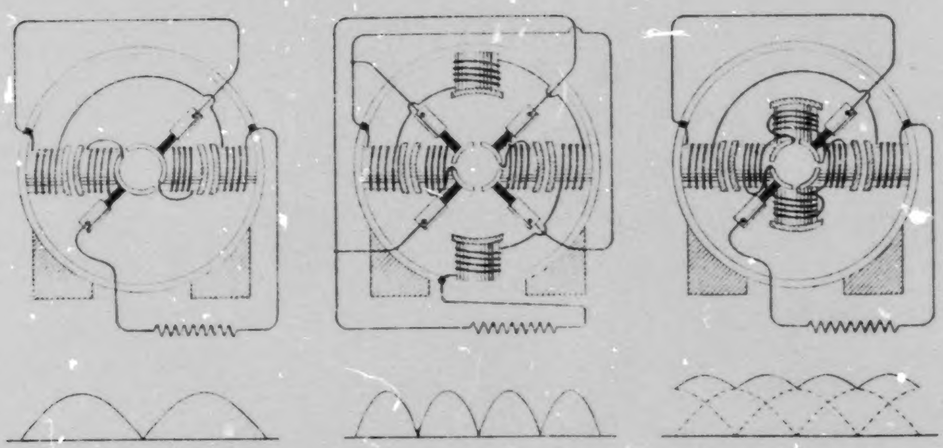


FIG. 2-6-12 BIPOLAR AND MULTIPOLAR DC GENERATOR

POSITIVE (+) BRUSH IS CONNECTED TO THE SIDE OF THE COIL MOVING UPWARD, WHILE THE NEGATIVE(-) BRUSH IS CONNECTED TO THE SIDE OF THE COIL MOVING DOWNWARD. THE POSITIVE BRUSH OF DC GENERATOR IS ALWAYS THE ONE FROM WHICH CURRENT FLOWS OUT TO THE EXTERNAL CIRCUIT; THE NEGATIVE BRUSH IS ALWAYS THE ONE TO WHICH CURRENT FLOWS BACK FROM THE EXTERNAL CIRCUIT. IF A DEMONSTRATION DC GENERATOR IS AVAILABLE, YOU CAN EXAMINE ITS PARTS AND SEE HOW IT WORKS.

DC GENERATOR, LIKE AN AC GENERATOR, MAY BE EITHER BIPOLAR OR MULTIPOLAR. SHOWN IN FIG. 2-6-12 IS HOW THE E.M.F. AND THE CURRENT SUPPLIED BY A BIPOLAR DC GENERATOR FLUCTUATE AS THE GENERATOR TURNS. FROM THE DIAGRAM WE KNOW THAT INCREASING THE NUMBER OF FIELD POLES INCREASES THE FREQUENCY OF PULSATING DIRECT CURRENT, WHILE INCREASING THE NUMBER OF ARMATURE COILS PRODUCES A SMOOTHER, STRONGER CURRENT THAT NEVER DROPS TO ZERO, AS SHOWN BY THE SOLID LINE IN THE GRAPH AT THE RIGHT. MULTIPOLAR GENERATORS HAVE MANY POLES AND MANY ARMATURE COILS.

D. SELF EXITED GENERATOR: SHOWN IN FIG. 2-6-13 ARE THE THREE TYPES OF SELF EXITED GENERATORS.

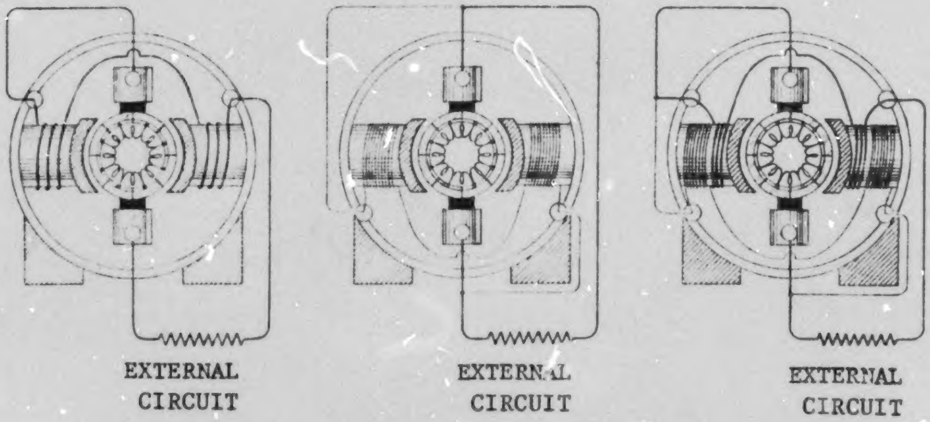


FIG. 2-6-13 TYPES OF SELF EXITED GENERATORS

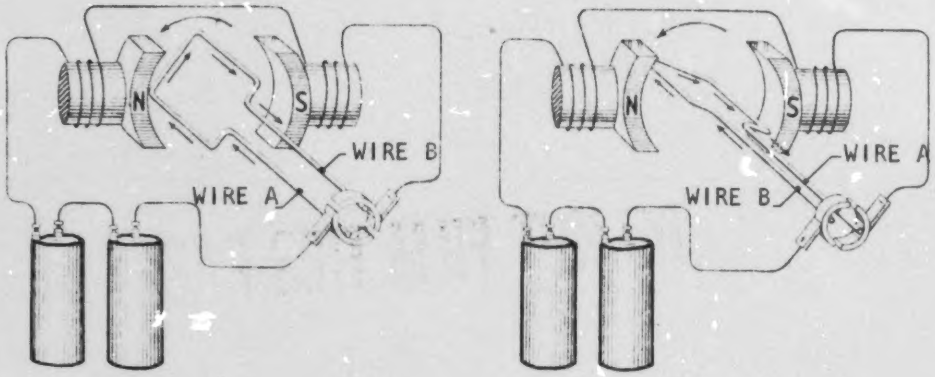
1. THE PERIES GENERATOR: THE FIELD COILS ARE IN THE SERIES WITH THE ARMATURE COILS.
2. THE SHUNT GENERATOR: THE FIELD COILS ARE IN PARALLEL WITH THE ARMATURE COILS.
3. THE COMPOUND GENERATOR: IT HAS TWO SETS OF FIELD COILS, ONE SET IN SERIES WITH THE ARMATURE COILS AND ONE SET IN PARALLEL WITH THEM.

III. DC MOTORS

A. INTRODUCTION: AS WE KNOW A GENERATOR CHANGES MECHANICAL ENERGY TO ELECTRICAL ENERGY BY MEANS OF MAGNETISM, WHILE A MOTOR DOES JUST THE OPPOSITE: IT CHANGES ELECTRICAL ENERGY TO MECHANICAL ENERGY BY MEANS OF MAGNETISM. DIRECT-CURRENT MOTORS ARE WIDELY USED IN ROBOTIC APPLICATIONS TODAY FOR TWO MAJOR REASONS:

1. THEIR SPEED-TORQUE RELATIONSHIP CAN BE VARIED, PROVIDING A WIDE RANGE OF APPLICATION.
2. THEY ARE READILY ADAPTABLE TO A VARIETY OF CONTROL CIRCUITS, ESPECIALLY SIMPLE LOGIC AND MICROPROCESSOR CONTROL.

B. PRINCIPLE: A DIRECT CURRENT MOTOR HAS EXACTLY THE SAME PARTS AS A DIRECT-CURRENT GENERATOR: FIELD MAGNETS, ARMATURE AND COMMUTATOR AND BRUSHES. THE FIELD MAGNETS MAY BE EITHER PERMANENT MAGNETS OR ELECTROMAGNETS. AS YOU MIGHT GUESS, ELCTROMAGNETS PROVIDE THE FIELD IN ALL POWERFUL MOTORS. THE FIELD MAGNETS MAY BE BIPOLAR OR MULTIPOLAR, DEPENDING ON THE USE FOR WHICH THE MOTOR IS INTENDED. MULTIPOLAR FIELD MAGNETS ARE USED IN MOTORS THAT MUST PULL WITH GREAT FORCE AT SLOW SPEEDS. THE ARMATURE OF A DC MOTOR MAY ALSO BE BIPOLAR OR MULTIPOLAR; THAT IS, IT MAY HAVE TWO OR MORE COILS WOUND ON ITS CORE. USUALLY, THERE IS AN ODD NUMBER OF ARMATURE POLES. THIS ARRANGEMENT PREVENTS THE MOTOR FROM STOPPING ON DEAD CENTER; THAT IS, IN A POSITION IN WHICH IT WILL NOT TURN WHEN A CURRENT IS SENT THROUGH THE ARMATURE COILS. A BIPOLAR ARMATURE IS ON DEAD CENTER WHEN ITS POLES ARE DIRECTLY IN LINE WITH THE FIELD POLES. THE ARMATURE COILS ARE CONNECTED TO THE EXTERNAL CIRCUIT BY A COMMUTATOR AND BRUSHES, WHICH ARE JUST LIKE THOSE IN A DC GENERATOR. THERE IS AT LEAST ONE COMMUTATOR SEGMENT FOR EACH ARMATURE COIL. SHOWN IN FIG. 2-6-14 IS THE OPERATION OF A COMMUTATOR IN A SIMPLE DIRECT-CURRENT MOTOR.



(A) (B)

FIG. 2-6-14 A SIMPLE DIRECT-CURRENT MOTOR

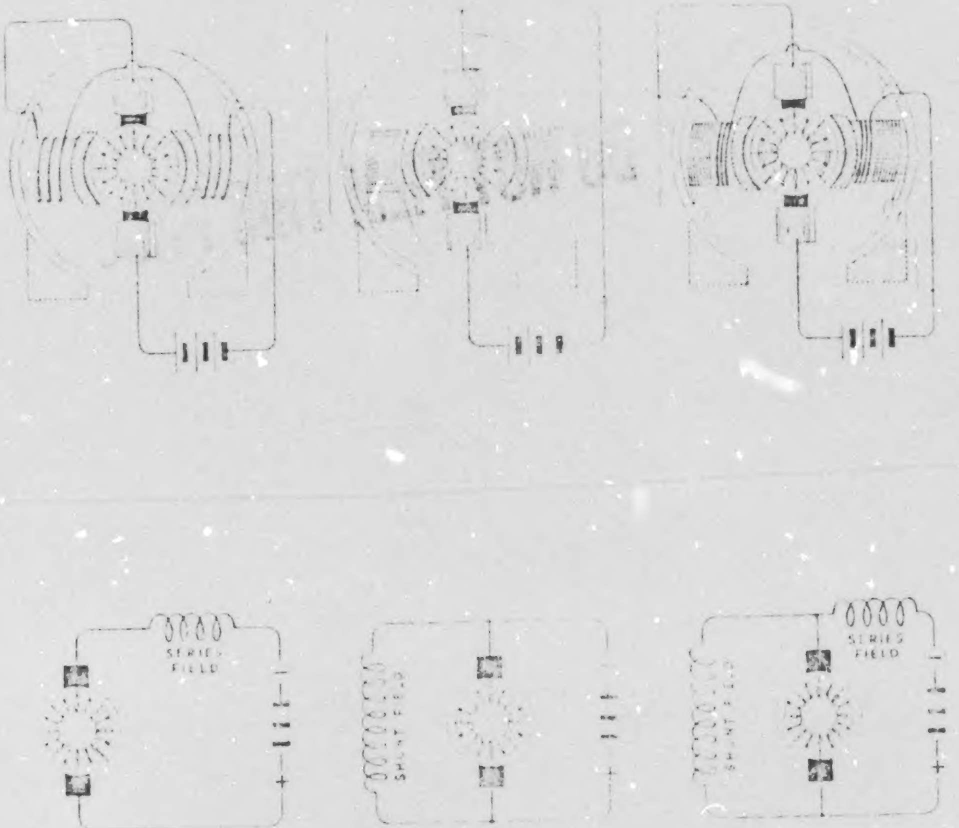
IN DIAGRAM (A) THE POSITIVE BRUSH IS CONNECTED TO WIRE A, AND THE NEGATIVE BRUSH TO WIRE B. IN DIAGRAM (B), THE LOOP HAS TURNED SO THAT THE COMMUTATOR CONNECTS THE POSITIVE BRUSH TO WIRE B, AND THE NEGATIVE ONE TO WIRE A. AS A RESULT, THE LOOP OF DIAGRAM (A) IS ALWAYS BEING PUSHED DOWN, WHILE THE DIAGRAM (B) IS BEING PUSHED UP--THUS CAUSING THE LOOP TURN. IN THESE DIAGRAMS THERE IS A SINGLE TURN OF WIRE FORAN ARMATURE COIL. ACTUALLY, THERE ARE MANY TURNS IN AN ARMATURE COIL, AND THE ARMATURE HAS AN IRON CORE. IN THE SIMPLE DC MOTOR, ITS ROTATION IS NOT STEADY. ITS OPERATION COULD BE IMPROVED BY ADDING ANOTHER COIL AT RIGHT ANGLES TO THE FIRST ONE OR BY ADDING SEVERAL COILS. THEN WITH THE PROPER CHANGES IN THE COMMUTATOR AND BRUSHES, AT LEAST ONE SET OF ARMATURE COILS WOULD BE PUSHED UP OR DOWN AT ALL TIMES. COMMERCIAL ELECTRIC MOTORS HAVE SEVERAL ARMATURE COILS WOUND WITH MANY TURNS OF WIRE ABOUT AN IRON CORE. A LARGE CURRENT IS SENT THROUGH THE COILS IN ORDER TO CHANGE LARGE AMOUNTS OF ELECTRICAL ENERGY INTO MECHANICAL ENERGY. A STRONG MAGNETIC FIELD IS SUPPLIED BY ELECTROMAGNETS, WHOSE MAGNETISM IS CONTROLLABLE. THUS THE MECHANICAL ENERGY SUPPLIED BY A MOTOR DEPENDS ON THREE THINGS: (1) THE NUMBER OF TURNS IN THE ARMATURE COILS, (2) THE AMOUNT OF CURRENT FLOWING THROUGH THE ARMATURE COILS, (3) THE STRENGTH OF THE FIELD MAGNETS.

OBVIOUSLY, USING AN IRON CORE IN THE ARMATURE WILL STRENGTHEN THE FIELD SET UP BY THE ARMATURE COIL. AS YOU KNOW, THE POLES OF A COIL ARE AT EITHER END. BY MEANS OF THE RIGHT-HAND RULE FOR COIL, YOU CAN DETERMINE THE POLARITY OF THE ARMATURE COIL WHEN CURRENT IS SENT THROUGH IT.

C. TYPES OF DC MOTORS: THE THREE BASIC DC MOTOR TYPES ARE THE SERIES-WOUND, SHUNT-WOUND AND COMPOUND-WOUND. THESE NAMES REFER TO THE MANNER IN WHICH COILS ARE CONNECTED IN REFERENCE TO THE ARMATURE, AS SHOWN IN FIG. 2-6-15. DIAGRAM (A) IS THE SERIES MOTOR, THE FIELD COILS ARE IN SERIES WITH THE ARMATURE COILS. DIAGRAM (B) IS THE SHUNT MOTOR, THE FIELD COILS ARE IN PARALLEL WITH THE ARMATURE COILS. DIAGRAM (C) IS THE COMPOUND MOTOR, IT HAS TWO SETS OF FIELD COILS AND ONE SET IS PARALLEL WITH THEM. DIAGRAMS (E), (F), AND (G) SHOW HOW THE FIELD COILS ARE CONNECTED TO THE COMMUTATOR BRUSHES IN EACH TYPE.

D. MOTOR SELECTION FACTORS: WHEN SELECTING A DC MOTOR FOR A GIVEN APPLICATION, THERE ARE SEVERAL FACTORS THAT MUST BE TAKEN INTO CONSIDERATION.

1. SPEED RANGE: IN APPLICATIONS REQUIRING A LARGE SPEED RANGE, AND WHERE FIELD-CONTROL IS USED, THE BASE SPEED MUST BE PROPORTIONATELY LOWER AND THE MOTOR SIZE MUST BE INCREASED. FOR SPEED RANGES OVER 3=1, ARMATURE-VOLTAGE CONTROL SHOULD BE CONSIDERED FOR AT LEAST A PORTION OF THE RANGE. UNLIMITED SPEED RANGE CAN BE OBTAINED USING ARMATURE-VOLTAGE CONTROL; HOWEVER, BELOW APPROXIMATELY 60% OF BASE SPEED, THE MOTOR RATING SHOULD BE DECREASED, OR THE MOTOR SHOULD ONLY BE USED FOR SHORT PERIODS OF TIME.
2. SPEED CONTROL UNDER LOAD: WHEN A SPECIFIC APPLICATION CALLS FOR CONSTANT SPEED UNDER VARYING LOAD CONDITIONS, A SHUNT-WOUND MOTOR SHOULD BE USED. IF MOTOR SPEED REGULATION MUST BE KEPT TO AN ABSOLUTE MINIMUM, A SPEED REGULATION CIRCUIT EMPLOYING TACHOMETER FEEDBACK MAY BE USED. IF THE APPLICATION REQUIRES A DECREASE IN MOTOR SPEED WHEN THE LOAD INCREASES, A SERIES--WOUND OR COMPOUND MOTOR MAY BE USED.


SERIES FIELD
SHUNT FIELD
SHUNT FIELD
SERIES FIELD
-
+
+
-
+

(A) (B) (C)

FIG. 2-6-15
TYPES OF DC MOTORS

E. DC BRUSHLESS MOTORS: THE DC MOTORS ALL HAVE ONE COMMON DISADVANTAGE; THEY USE A BRUSH-COMMUTATOR ASSEMBLY TO MECHANICALLY SWITCH THE ARMATURE CURRENT. BECAUSE OF THIS MECHANICAL SWITCHING ACTION, THE BRUSHES HAVE A LIMITED LIFE AND CAUSE COMMUTATOR WEAR. BESIDES THAT, BRUSH WEAR PRODUCES DUST, WHICH IN TURN CAN FOUL THE MOTOR BEARING AND ALSO CREATE A VOLTAGE LEAKAGE PATH. IN A CONTINUOUS ROTATING BRUSHLESS MOTOR, MECHANICAL SWITCHING IS REPLACED WITH ELECTRONIC SWITCHING. BRUSHLESS MOTORS ARE NOT SIMPLY AC MOTORS POWERED BY AN INVERTER, BUT HAVE POSITION FEEDBACK SO THAT THE IMPACT WAVEFORMS ARE KEPT IN PROPER TIMING WITH RESPECT TO ROTOR POSITION.

THE CONTINUOUS ROTATING BRUSHLESS MOTOR IS VERY POPULAR TODAY. FOR INSTANCE, IT ACCELERATES FROM ZERO TO OPERATING SPEED AS A PERMANENT MAGNET DC MOTOR; AND ONCE IT HAS REACHED OPERATING SPEED, IT CAN BE SWITCHED TO SYNCHRONOUS OPERATION OPERATED IN A PHASE-LOCKED LOOP. SOME BRUSHLESS MOTORS USE OPTICS AND PHOTOCELLS TO COMMUTATE THE MOTOR CURRENT, BUT THE TRANSISTOR SWITCHED MOTOR IS THE MOST COMMON.

IV. STEPPING MOTORS

A. INTRODUCTION

1. STEPPING MOTORS ARE BECOMING INCREASINGLY POPULAR IN INDUSTRIAL APPLICATIONS WHERE COMPUTER CONTROL IS THE NORM. THEY OFFER SIGNIFICANT ADVANTAGES OVER THE USUAL CLOSED-LOOP SERVOMOTOR SYSTEM FOUND IN MANY INDUSTRIAL CONTROL SETTINGS. WITH STEPPERS, FEEDBACK SIGNALS ARE NOT REQUIRED, AND MOTOR ERROR IS NON-CUMULATIVE AS LONG AS PULSE-TO-STEP INTEGRITY IS MAINTAINED. FOR EXAMPLE, A TRAIN OF PULSES CAN BE COUNTED INTO A STEPPER, AND ITS RESULTANT FINAL POSITION WILL BE KNOWN WITHIN A SMALL PERCENTAGE OF ONE STEP.

B. DEFINITION: A STEPPING MOTOR IS A MOTOR THAT HAS THE CAPABILITY OF ROTATING IN EITHER DIRECTION, STARTING OR STOPPING AT VARIOUS MECHANICAL POSITIONS, MOVING ITS ROTOR IN PRECISE ANGULAR INCREMENTS OF EACH INPUT EXITATION CHANGE OR STEP. THE PRECISE ANGULAR MOVEMENT IS REPEATED FOR EACH INPUT STEP COMMAND, WHICH RESULTS IN THE MOTOR'S ABILITY TO ACCURATELY POSITION ITS ROTOR IN A KNOWN REPEATABLE DIRECTION. IN A STEPPER MOTOR, THE ROTOR POSITION, SPEED, DIRECTION, AND DISTANCE OF ANGULAR TRAVEL ARE EASY TO CONTROL. THE NUMBER OF STEPS REQUIRED TO COMPLETE ONE REVOLUTION OF THE ROTOR VARIES, DEPENDING ON THE SPECIFIC MOTOR AND ITS INTENDED APPLICATION.

C. STEPPER MOTOR SPECIFICATION: THE STEPS PER REVOLUTION AND THE STEP ANGLE OF THE STEPPER MOTORS ARE SHOWN IN FIG. 2-6-16.

STEPS PER REVOLUTION	INCREMENTAL ANGLE PER STEP
240	1.5°
180	2.0°
144	2.5°
72	5.0°
48	7.5°
24	15°
12	30°

FORMULA:

$$\text{ANGLE PER STEP} = \frac{360^\circ}{5}$$

WHERE S=STEPS

FOR EXAMPLE: $\frac{360}{180} = 2^\circ$

FIG. 2-6-16 TYPICAL STEPPER MOTOR SIZE

THERE ARE MANY TYPES OF STEPPING MOTORS, BUT THEY CAN ALL BE GROUPED ONTO THREE MAJOR CLASSIFICATIONS:

1. BIPOLAR PERMANENT MAGNET STEPPING MOTOR
2. VARIABLE RELUCTANCE STEPPING MOTOR
3. BIFILAR STEPPING MOTOR

LESSON PLAN #6

UNIT 2-- DC POWER

ASSIGNMENT SHEET 1

AFTER READING THE INFORMATION SHEET (IS2-6-1 AND IS2-6-3) PROVIDED, COMPLETE THE FOLLOWING QUESTIONS IN WRITING OR AS REQUESTED BY YOUR INSTRUCTOR.

1. DEFINITION:
    A. CELL-

    B. ELECTRODE-

    C. PRIMARY CELL-

    D. SECONDARY CELL-

    E. CAPACITY-

2. THERE ARE THREE TYPES OF SELF EXITED GENERATORS. WHAT ARE THEY?

3. WHAT ARE THE TWO MAJOR REASONS OF DC MOTORS TO BE WIDELY USED IN ROBOTIC APPLICATION?

4. THE DC MOTOR HAS EXACTLY THE SAME PARTS AS A DC GENERATOR; THEY ARE:

5. WHAT ARE THE THREE BASIC TYPES OF DC MOTORS?

6. A STEPPING MOTOR HAS 240 STEPS PER REVOLUTION. COMPUTE HOW MANY DEGREES PER STEP FOR ROTATING.

SYLLABUS SHEET FOR LESSON 4
ROBOT SERVICE AND REPAIR

UNIT # 3 ROBOT CONTROL SYSTEM

INTRODUCTION TO PROGRAMMING

LESSON OBJECTIVE--UPON COMPLETION OF THIS LESSON, THE STUDENT SHOULD BE ABLE TO:

1. VERBALLY DEFINE THE TERMS: INSTRUCTION, PROGRAM, WORD, BYTE, MPU, MEMORY, BUS, ADDRESS, OPERAND, OPCODE, ETC.
2. DEVELOP FLOW CHARTS THAT ILLUSTRATE STEP BY STEP PROCEDURE FOR SOLVING SIMPLE PROBLEMS.
3. WRITE A SIMPLE PROGRAM THAT CAN MULTIPLY BY REPEATED ADDITION; DIVIDE BY REPEATED SUBTRACTION, ETC.

TEACHING AIDS:

H3-4-1	SYLLABUS SHEET
T3-4-1	A BASIC MICROCOMPUTER
T3-4-2	ARITHMETIC LOGIC UNIT
T3-4-3	THE RANDOM ACCESS MEMORY
T3-4-4	MICROCOMPUTER OPERATION
T3-4-5	INSTRUCTION AND DATA FORMAT
T3-4-6	THE PROGRAM IN MEMORY
T3-4-7	THE SEQUENCE OF INSTRUCTION
T3-4-8	DIRECT ADDRESSING MODE INSTRUCTIONS
T3-4-9	FLOW CHART OF MULTIPLYING BY REPEATED ADDITION
T3-4-10	FLOW CHART OF DIVIDING BY REPEATED SUBTRACTION

INFORMATIONAL ASSIGNMENT:

IS3-4-1	MICROCOMPUTER AND PROGRAM CONCEPTS
IS3-4-2	THE TYPES OF OPERATIONS THAT THE MICROCOMPUTER PERFORMS
IS3-4-3	PROGRAMMING FUNDAMENTALS
IS3-4-4	ARITHMETIC PROBLEMS
	ANSWER QUESTIONS FOUND ON ASSIGNMENT SHEETS
AS3-4-1	INTRODUCTION TO PROGRAMMING

REFERENCES:

LEVENTHAL, L.A., 6800 ASSEMBLY LANGUAGE PROGRAMMING. OSBORNE AND ASSOCIATES, INC., CALIFORNIA, 1978.

RONY, P.R., INTRODUCTORY EXPERIMENTS IN DIGITAL ELECTRONICS AND 8080A MICROCOMPUTER PROGRAMMING AND INTERFACING. HOWARD W. SAMS AND CO., INC., INDIANA, 1982.

STOCKHAHN, A.D. AND OTTER, J.D., INDUSTRIAL APPLICATIONS FOR MICROPROCESSORS. RESTON PUBLISHING CO., INC. VIRGINIA, 1982.

STEP-INTRODUCTION FOR PREPARATION OF THE STUDENT:

MOST OF TODAY'S MORE SOPHISTICATED ROBOTS USE SOME SORT OF COMPUTER CONTROL. THROUGH PROGRAMMING A MICROPROCESSOR, THIS ALLOWS A ROBOT TO PERFORM SPECIFIC PREDETERMINED TASKS. ALSO, BY ITS INTERFACING ABILITY, THE MICROPROCESSOR ALLOWS A ROBOT TO ESTABLISH COMMUNICATIONS AND FUNCTION WITH THE OUTSIDE WORLD. IN THIS UNIT, THE STUDENT WILL LEARN TO PROGRAM THE MICROPROCESSOR. THE PROGRAMS ARE VERY SIMPLE. BY STUDYING THESE PROGRAMS, THE STUDENT WILL DEVELOP AN UNDERSTANDING OF HOW THE MICROPROCESSOR HANDLES MORE COMPLEX TASKS. BY THE WAY, THE STUDENTS WILL GAIN PRACTICE USING THE INSTRUCTION SET.

LESSON SUMMARY AND REVIEW:

1. WHAT ARE THE THREE TYPES OF BUSES USED IN A MICROCOMPUTER?

2. THE PORTIONS OF THE MICROCOMPUTER IN WHICH INSTRUCTIONS AND DATA ARE STORED IN ARE CALLED THE:

3. IN MICROPROCESSOR TERMINOLOGY, THE NUMBER OR PIECE OF DATA THAT IS IN OPERATION IS CALLED THE:

4. IN THE IMMEDIATE ADDRESSING MODE, THE SECOND BYTE OF THE INSTRUCTION IS THE ____.

5. ______ IS NORMALLY A 1-BYTE INSTRUCTION.

6. A DISADVANTAGE OF DIRECT ADDRESSING IS THAT THE OPERAND MUST BE IN THE FIRST ______ BYTE'S OF MEMORY.

7. COMPLETE THE FOLLOWING INSTRUCTIONS AND DATA FORMAT.

D_7							D_0	OPCODE

( ) INSTRUCTION

BYTE ONE	D_7							D_0	( )
BYTE TWO	D_7							D_0	( )

( ) INSTRUCTION

BYTE ONE									OPCODE
BYTE TWO									
BYTE THREE									

( )

MICROCOMPUTER AND PROGRAM CONCEPT

I. MICROCOMPUTER. AS MENTIONED BEFORE, THE MICROPROCESSOR UNIT OR MPU, IS C COMPLEX LOGIC ELEMENT THAT PERFORMS ARITHMETIC, LOGIC, AND CONTROL FUNCTIONS. THE TREND IS TO PACKAGE IT AS A SINGLE INTERGRATED CIRCUIT. A MICROCOMPUTER CONTAINS A MICROPROCESSOR, BUT IT ALSO CONTAINS OTHER CIRCUITS SUCH AS MEMORY DEVICES TO STORE INFORMATION, INTERFACE ADAPTERS TO CONNECT IT WITH THE OUTSIDE WORLD, AND A CLOCK TO ACT AS A MASTER TIMER FOR THE SYSTEM. MICROCOMPUTERS ARE USED TO CONTROL ONE OR MORE ROBOTS.

TYPICAL MICROCOMPUTERS IN WHICH THESE ADDITIONAL CIRCUITS ARE ADDED--(AS SHOWN IN FIG. 3-4-1)

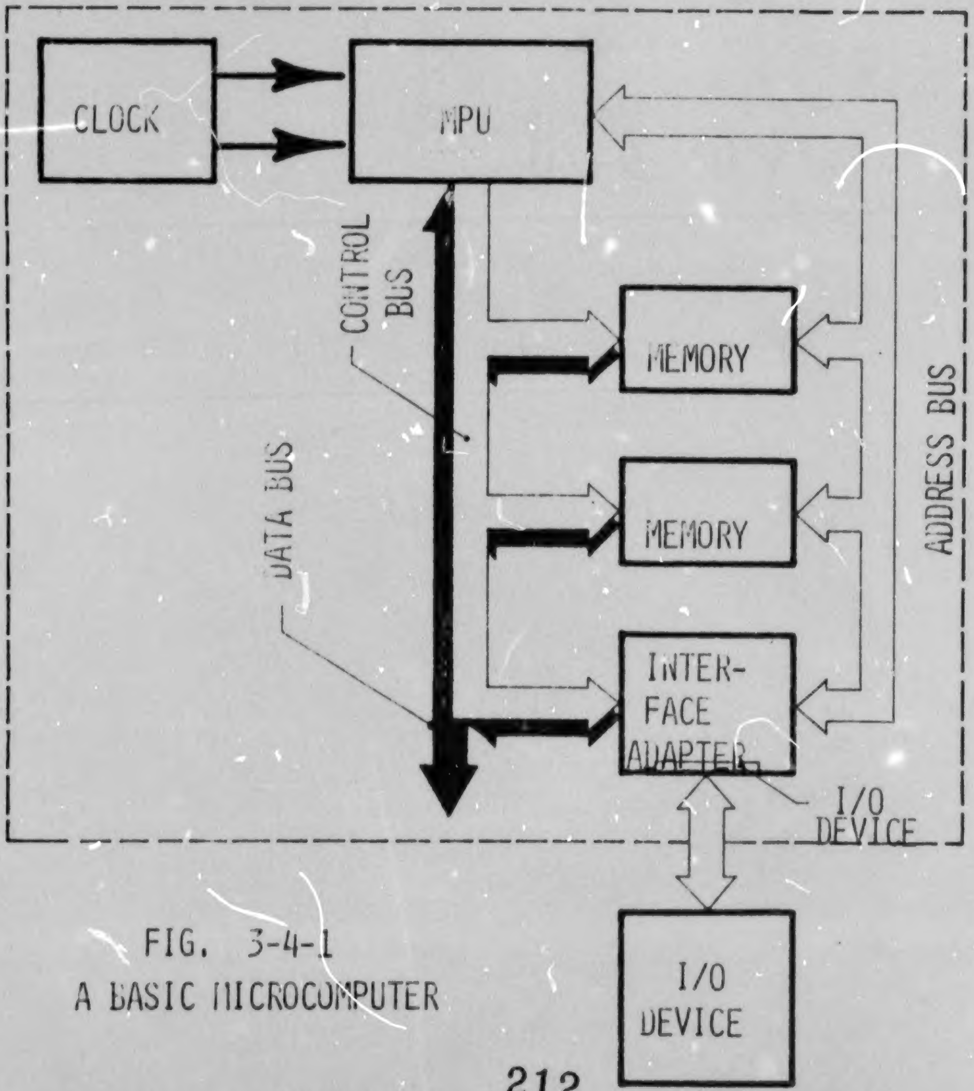

CLOCK
MPU
CONTROL BUS
MEMORY
MEMORY
ADDRESS BUS
DATA BUS
INTER-FACE ADAPTER
I/O DEVICE
I/O DEVICE

FIG. 3-4-1
A BASIC MICROCOMPUTER

THE ARROWS REPRESENT CONDUCTORS OVER WHICH BINARY INFORMATION FLOWS. THE WIDE ARROWS REPRESENT SEVERAL CONDUCTORS CONNECTED IN PARALLEL. A GROUP OF PARALLEL CONDUCTORS THAT TRANSFER DIGITAL INFORMATION IS CALLED BUS. THERE ARE THREE TYPES OF BUSES USED IN A MICROCOMPUTER.

A. DATA BUS--A DATA BUS IN WHICH DIGITAL INFORMATION CAN BE TRANSFERRED IN EITHER DIRECTION. IT IS A BIDIRECTIONAL DATA PATH BY WHICH DATA IS TRANSFERRED BETWEEN THE MPU, MEMORY, AND I/O DEVICES.

B. ADDRESS BUS--AN UNDIRECTIONAL BUS OVER WHICH DIGITAL INFORMATION APPEARS TO IDENTIFY EITHER A PARTICULAR MEMORY LOCATION OR A I/O DEVICES.

C. CONTROL BUS--A SET OF SIGNALS THAT REGULATE THE OPERATION OF A MICROCOMPUTER SYSTEM, INCLUDING I/O DEVICES AND MEMORY. THEY FUNCTION MUCH LIKE "TRAFFIC" SIGNALS OR COMMANDS.

II. MICROCOMPUTER PROGRAMMING. A MICROCOMPUTER IS CAPABLE OF PERFORMING MANY DIFFERENT OPERATIONS. IT CAN ADD AND SUBTRACT NUMBERS, PERFORM LOGIC OPERATIONS, READ INFORMATION FROM AN INPUT DEVICE, AND TRANSMIT INFORMATION TO AN OUTPUT DEVICE. IN SPITE OF ALL ITS CAPABILITIES, THE COMPUTER WILL DO NOTHING ON ITS OWN ACCORD. IT WILL DO ONLY WHAT IT IS TOLD TO DO, NOTHING MORE AND NOTHING LESS. THE USER MUST TELL THE COMPUTER EXACTLY WHAT OPERATION TO PERFORM AND THE ORDER IN WHICH IT SHOULD PERFORM THEM. THE OPERATION THAT A COMPUTER CAN BE TOLD TO PERFORM ARE CALLED INSTRUCTIONS. A FEW TYPICAL INSTRUCTIONS ARE ADD--SUBTRACT--LOAD--INDEX--REGISTER--STORE--ACCUMULATOR--AND HALT.

A PROGRAM IS A GROUP OF INSTRUCTION THAT ALLOWS THE COMPUTER TO PERFORM A SPECIFIC JOB. ONE WHO WRITES THESE INSTRUCTIONS IS CALLED A PROGRAMMER.

GENERALLY, THE LENGTH OF THE PROGRAM IS PROPORTIONAL TO THE COMPLEXITY OF THE TASK THE COMPUTER IS TO PERFORM. A PROGRAM FOR ADDING A LIST OF NUMBERS MAY REQUIRE ONLY A DOZEN INSTRUCTIONS. ON THE OTHER HAND, A PROGRAM FOR CONTROLLING A ROBOT DURING PAINTING OPERATIONS MAY REQUIRE HUNDREDS OF INSTRUCTIONS. SIMPLE PROGRAMS AND SUBROUTINES CAN BE WRITTEN AS EASILY AND QUICKLY IN ASSEMBLY LANGUAGE AS THEY CAN IN A HIGHER LEVEL LANGUAGE. SUCH PROGRAMS ARE ALSO EXECUTED MORE QUICKLY, REQUIRE LESS MEMORY, AND ARE PROBABLY EASIER TO UNDERSTAND.

III. COMPUTER WORDS AND WORD LENGTHS. IN COMPUTER TERMINOLOGY, A WORD IS A GROUP OF BINARY DIGITS THAT CAN OCCUPY A STORAGE LOCATION. ALTHOUGH THE WORD MAY BE MADE UP OF SEVERAL BINARY DIGITS, THE COMPUTER HANDLES EACH WORD AS IF IT WERE A SINGLE UNIT. THUS, THE WORD IS THE FUNDAMENTAL UNIT OF INFORMATION USED IN THE COMPUTER. A WORD MAY BE A BINARY NUMBER THAT IS THEN TO BE HANDLED AS DATA, OR THE WORD MAY BE AN ASCII CHARACTER REPRESENTING A LETTER OF THE ALPHABET. FINALLY, A WORD CAN BE AN ADDRESS THAT TELLS THE COMPUTER WHERE A PIECE OF DATA IS LOCATED.

IN THE PAST FEW YEARS, A WIDE VARIETY OF MICROPROCESSORS HAVE BEEN DEVELOPED. THEIR COST, CHARACTERISTICS, AND CAPABILITIES VARY WIDELY. ONE OF THE MOST IMPORTANT CHARACTERISTICS OF ANY MICROPROCESSOR IS THE WORD LENGTH IT CAN HANDLE. THIS REFERS TO THE LENGTH (IN BIT) OF THE MOST FUNDAMENTAL UNIT OF INFORMATION. THE MOST COMMON WORD LENGTH FOR MICROPROCESSORS IS 8 BITS. THAT IS THE NUMBERS, ADDRESSES, INSTRUCTIONS AND DATA ARE REPRESENTED BY 8 BIT BINARY NUMBERS. BESIDES 8 BIT WORD LENGTH, THERE ARE OTHER WORD LENGTHS SOMETIMES ALSO USED. THE EARLIEST MICROPROCESSORS USED A 4 BIT WORD LENGTH, EVEN NOW THEY ARE STILL USED IN MANY CASES BECAUSE OF THEIR LOW COST. A LONGER WORD LENGTH, SAY 16 BIT MICROPROCESSOR, HAS BECOME INCREASINGLY POPULAR. THE LONGER WORD LENGTHS ALLOW US TO WORK WITH LARGER NUMBERS. FOR EXAMPLE, A 16-BIT WORD CAN REPRESENT DECIMAL NUMBERS UP TO 65535. BUT, THIS CAPABILITY ADDS TO THE COMPLEXITY AND THE COST OF THE MICROPROCESSOR.

THE TWO OPERANDS MAY BE ADDED, SUBTRACTED, OR COMPARED IN SOME WAY, AND THE RESULT OF THE OPERATION IS STORED IN THE BACK OF THE ACCUMULATOR. FOR EXAMPLE: $8_{10}+5_{10}=13_{10}$. THIS IS SHOWN IN FIG. 3-4-2, THE SUM IS STORED IN THE ACCUMULATOR, REPLACING THE OPERAND. NOTICE THAT ALL THE NUMBERS INVOLVED ARE IN BINARY FORM.

B. ACCUMULATOR. THIS IS THE MOST USEFUL REGISTER IN THE MICROPROCESSOR. DURING ARITHMETIC AND LOGIC OPERATIONS, IT PERFORMS A DUAL FUNCTION. BEFORE THE OPERATION, IT HOLDS ONE OF THE OPERANDS. AFTER THE OPERATION, IT HOLDS THE RESULTING SUM, DIFFERENCE, OR LOGIC ANSWER.

C. DATA REGISTER. THIS IS A TEMPORARY STORAGE LOCATION FOR THE DATA GOING TO OR COMING FROM THE DATA BUS. FOR INSTANCE, IT HOLDS AN INSTRUCTION WHILE THE INSTRUCTION IS BEING DECODED; ALSO, IT HOLDS A DATA BYTE WHILE THE WORD IS BEING STORED IN MEMORY. THE MPU ALSO CONTAINS SEVERAL OTHER IMPORTANT REGISTERS AND CIRCUITS: THE REGISTER, THE PROGRAM COUNTER, THE INSTRUCTION DECODER, AND THE CONTROLLER SEQUENCER.

D. MEMORY. AS SHOWN IN FIG. 3-4-3, (A SIMPLIFIED DIAGRAM OF THE 256 WORD, 8 BIT READ/WRITE MEMORY), THE MEMORY CONSISTS OF FF_{16} OR 256_{10} LOCATIONS, EACH OF WHICH CAN STORE AN 8 BIT WORD. A READ/WRITE MEMORY ON WHICH DATA CAN BE WRITTEN AND READ OUT WITH EQUAL EASE. TWO BUSES AND A NUMBER OF CONTROL LINES CONNECT THE MEMORY WITH THE MICROPROCESSING UNIT. THE ADDRESS BUS WILL CARRY A 8 BIT BINARY NUMBER FROM THE MPU TO THE MEMORY ADDRESS DECODER. THE ADDRESS DECODER AND THE 8 BIT NUMBER SELECTS THE PROPER MEMORY LOCATION. THE MEMORY ALSO RECEIVES A CONTROL SIGNAL FROM THE MPU. THIS SIGNAL TELLS THE MEMORY WHICH OPERATION IS TO BE PERFORMED. FOR EXAMPLE, A READ SIGNAL INDICATES THAT THE SELECTED LOCATION IS TO BE READ OUT. THAT MEANS THE 8 BIT NUMBER CONTAINED IN THE SELECTED LOCATION IS TO BE PLACED ON THE DATA BUS WHERE IT CAN BE TRANSFERRED TO THE MPU.

THE MPU CAN ALSO INITIATE A WRITE OPERATION. A WRITE SIGNAL INDICATES THAT A DATA WORD IS TAKEN FROM THE DATA BUS AND PLACED IN THE SELECTED MEMORY LOCATION. IN THIS CASE,

THE RANDOM ACCESS MEMORY

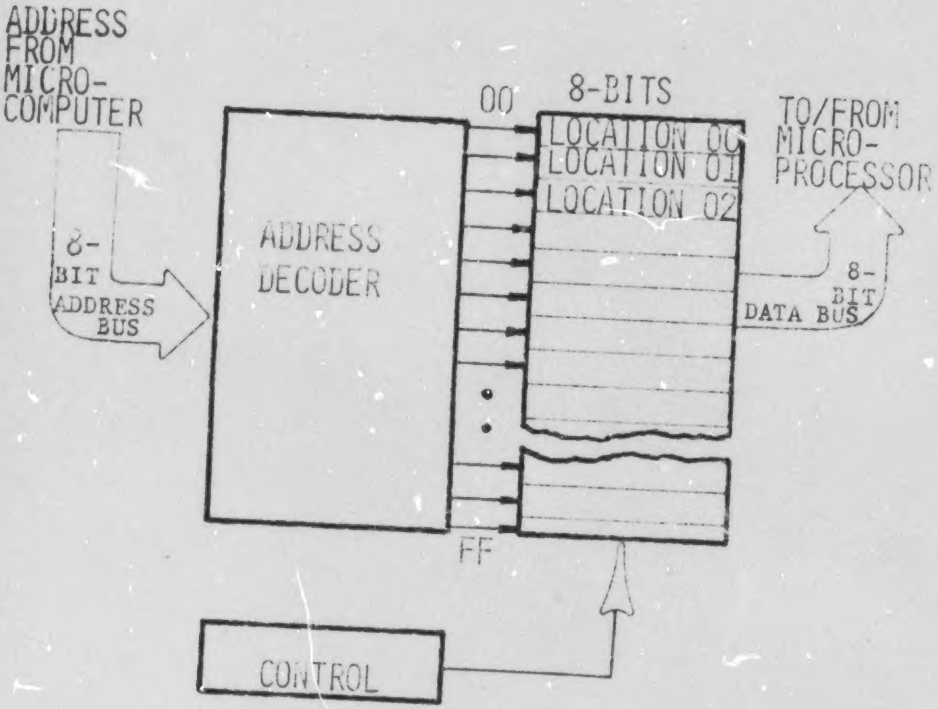

ADDRESS FROM MICRO-COMPUTER
8-BIT ADDRESS BUS
ADDRESS DECODER
00
FF
8-BITS
LOCATION 00
LOCATION 01
LOCATION 02
TO/FROM MICRO-PROCESSOR
8-BIT DATA BUS
CONTROL

FIG. 3-4-3

READ/WRITE COMMAND
FROM MICROPROCESSOR

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THE PREVIOUS CONTENTS OF THE SELECTED LOCATION ARE LOST AS THE NEW NUMBER IS WRITTEN IN THAT LOCATION.

ACTUALLY THERE ARE TWO CLASSIFICATIONS OF MEMORY WHICH MUST BE CONSIDERED IN ORDER TO UNDERSTAND THE MICROCOMPUTER.

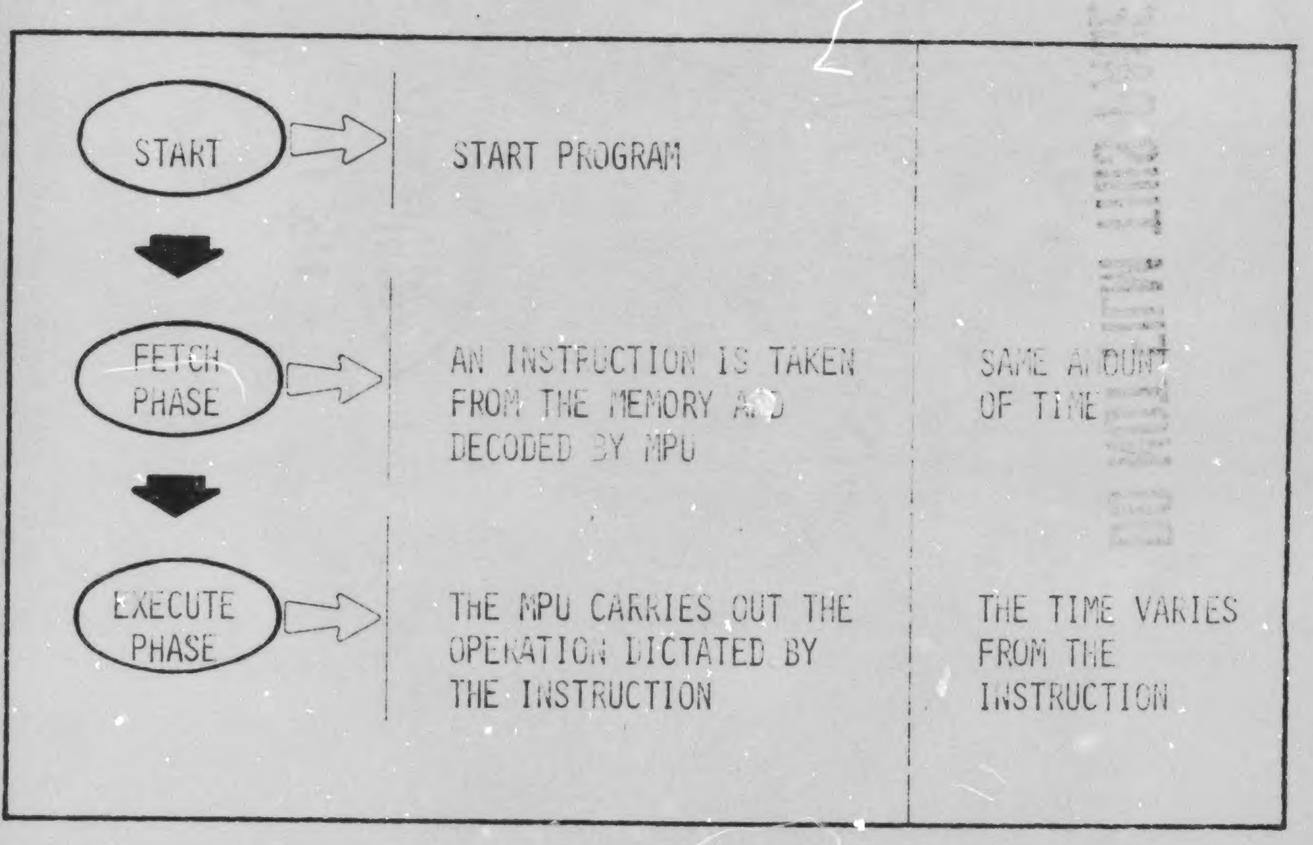
** RAM--ACTS AS A TEMPORARY STORAGE LOCATION WITHIN THE MICROCOMPUTER.

** ROM--IS A PERMANENT STORAGE AREA FOR PROGRAMS OR CONTENTS THAT ARE ESSENTIAL FOR THE OPERATION OF THE MICROCOMPUTER. AS THE NAME INPLIES, INFORMATION CAN ONLY BE READ FROM THIS TYPE OF MEMORY.

E. FETCH-EXECUTIVE SEQUENCE. WHEN THE MICROCOMPUTER IS EXECUTING A PROGRAM, IT GOES THROUGH A FUNDAMENTAL SEQUENCE THAT IS REPEATED OVER AND OVER AGAIN. A PROGRAM CONSISTS OF INSTRUCTIONS THAT TELL THE MICROCOMPUTER EXACTLY WHAT OPERATIONS TO PERFORM. THESE INSTRUCTIONS MUST BE STORED IN AN ORDERLY MANNER IN MEMORY. INSTRUCTIONS MUST BE "FETCHED" ONE AT A TIME FROM MEMORY, BY THE MPU. THE MPU THEN "EXECUTES" THE INSTRUCTION.

THE OPERATION OF THE MICROCOMPUTER CAN BE BROKEN DOWN INTO TWO PHASES, AS SHOWN IN FIG. 3-4-4.

MICROCOMPUTER OPERATION



START	START PROGRAM	
FETCH PHASE	AN INSTRUCTION IS TAKEN FROM THE MEMORY AND DECODED BY MPU	SAME AMOUNT OF TIME
EXECUTE PHASE	THE MPU CARRIES OUT THE OPERATION DICTATED BY THE INSTRUCTION	THE TIME VARIES FROM THE INSTRUCTION

FIG. 3-4-4

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THE TYPES OF OPERATIONS THE MICROPROCESSOR PERFORMS

1. MOVE A BYTE FROM ONE LOCATION TO ANOTHER.
   - --FROM ONE GENERAL PURPOSE REGISTER TO ANOTHER.
   - --FROM A GENERAL PURPOSE REGISTER TO MEMORY AND VICE VERSA.
   - --FROM THE ACCUMULATOR TO MEMORY, AND VICE VERSA.
   - --FROM THE ACCUMULATOR TO A GENERAL PURPOSE REGISTER, AND VICE VERSA.
   - --FROM MEMORY TO THE INSTRUCTION REGISTER.
   - --FROM MEMORY TO THE PROGRAM COUNTER, AND VICE VERSA.
   - --FROM MEMORY TO THE STACK POINTER.
   - --FROM THE ACCUMULATOR TO AN OUTPUT LATCH.
   - --FROM AN INPUT DEVICE TO THE ACCUMULATOR.
   - --FROM AN EXTERNAL THREE-STATE BUFFER TO THE INSTRUCTION REGISTER.
   - --FROM THE GENERAL PURPOSE REGISTER TO THE STACK POINTER.
   - --FROM THE FLAG REGISTER TO MEMORY, AND VICE VERSA.
   - --FROM THE PROGRAM COUNTER TO THE STACK, AND VICE VERSA.
   - --FROM THE GENERAL PURPOSE REGISTER TO THE STACK, AND VICE VERSA.
   - --FROM THE FLAG REGISTER TO THE STACK, AND VICE VERSA.
   - --FROM AN INPUT DEVICE TO A GENERAL PURPOSE REGISTER.
   - --FROM A GENERAL PURPOSE REGISTER TO THE PROGRAM COUNTER.
   - --FROM A GENERAL PURPOSE REGISTER TO AN OUTPUT DEVICE.
2. ARITHMETIC AND LOGICAL OPERATIONS.
   - --AND CONTENTS OF REGISTER OR MEMORY WITH ACCUMULATOR.
   - --OR CONTENTS OF REGISTER OR MEMORY WITH ACCUMULATOR.
   - --EXCLUSIVE OR CONTENTS OR REGISTER OR MEMORY WITH ACCUMULATOR.
   - --COMPARE CONTENTS OF REGISTER OR MEMORY WITH ACCUMULATOR.
   - --ADD CONTENTS OF REGISTER OR MEMORY TO ACCUMULATOR (WITH OR WITHOUT BORROWS).
   - --ROTATE CONTENTS OF ACCUMULATOR.
   - --INCREMENT CONTENTS OF GENERAL PURPOSE REGISTER, REGISTER PAIR, ACCUMULATOR, MEMORY OR STACK POINTER.
   - --DECREMENT CONTENTS OF GENERAL PURPOSE REGISTER, REGISTER PAIR, ACCUMULATOR, MEMORY, OR STACK POINTER.
   - --ADD CONTENTS OF REGISTER PAIR TO CONTENTS OF REGISTER PAIR OR STACK POINTER.
   - --DECIMAL ADJUST THE CONTENTS OF THE ACCUMULATOR.

3. MISCELLANEOUS OPERATION

- --NO OPERATION
- --HALT
- --ENABLE THE INTERRUPT SYSTEM
- --DISABLE THE INTERRUPT SYSTEM
- --COMPLEMENT THE ACCUMULATOR
- --SET THE CARRY
- --COMPLEMENT THE CARRY

PROGRAMMING FUNDAMENTALS

I. INSTRUCTION SET. BEFORE YOU CAN WRITE THE PROGRAM, YOU MUST KNOW WHAT INSTRUCTIONS ARE AVAILABLE TO YOU AND THE COMPUTER. EVERY MICROPROCESSOR COMES WITH A LIST OF ITS INSTRUCTION SET. AS MENTIONED BEFORE, A COMPUTER, NO MATTER HOW SOPHISTICATED, CAN ONLY DO WHAT IT IS "TOLD" TO DO. ONE "TELLS" THE COMPUTER WHAT TO DO VIA A SERIES OF CODED INSTRUCTIONS REFERRED TO AS A PROGRAM. THE REALM OF THE PROGRAMMER IS REFERRED TO AS SOFTWARE, IN CONTRAST TO THE HARDWARE THAT COMPRISES THE ACTUAL COMPUTER EQUIPMENT.

EACH COMPUTER INSTRUCTION ALLOWS THE PROGRAMMER TO INITIATE THE PERFORMANCE OF A SPECIFIC OPERATION. ALL COMPUTERS IMPLEMENT CERTAIN ARITHMETIC OPERATIONS IN THEIR INSTRUCTION SET, SUCH AS AN INSTRUCTION TO ADD THE CONTENTS OF TWO REGISTERS.

II. INSTRUCTION CODE MNEMONICS. AN OBVIOUS PROGRAMMING IMPROVEMENT IS TO ASSIGN A NAME TO EACH INSTRUCTION CODE. THE INSTRUCTION CODE NAME IS CALLED A MNEMONIC OR MEMORY AID. THE INSTRUCTION MNEMONIC SHOULD DESCRIBE IN SOME WAY WHAT THE INSTRUCTION DOES, IN FACT, EVERY MICROPROCESSOR MANUFACTURER PROVIDES A SET OF MNEMONICS FOR THE MICOPROCESSOR INSTRUCTION SET.

III. INSTRUCTION AND DATA FORMATS. MEMORY FOR MICROPROCESSOR USUALLY IS ORGANIZED INTO 8 BIT QUANTITIES, CALLED BYTE. EACH BYTE HAS A UNIQUE 16 BIT BINARY ADDRESS CORRESPONDING TO ITS SEQUENTIAL POSITION IN MEMORY. THE FORM OF 8 BIT BINARY REGISTERS IS AS FOLLOWS.

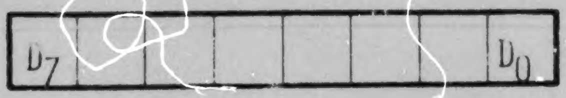
DATA WORD

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
MSB							LSB

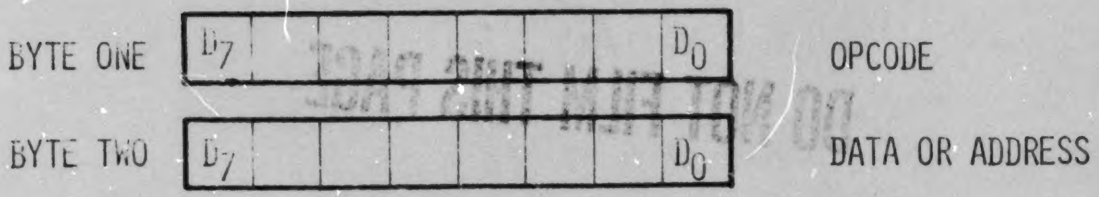
LSB: LEAST SIGNIFICANT BIT (BIT 0)

MSB: MOST SIGNIFICANT BIT (BIT 7)

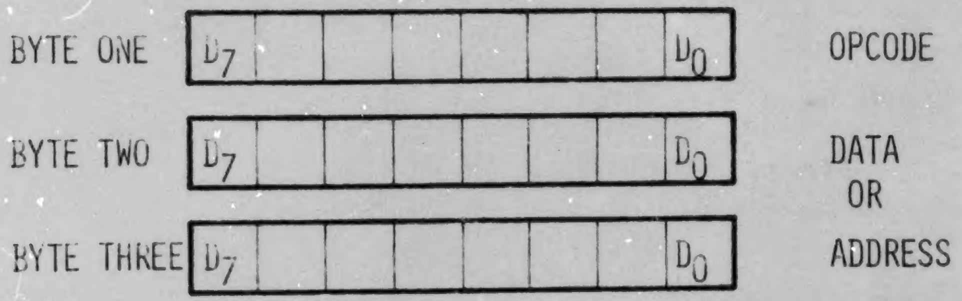
PROGRAM INSTRUCTIONS MAY BE ONE, TWO, OR THREE BYTES IN LENGTH. MULTIPLE BYTE INSTRUCTIONS MUST BE STORED IN SUCCESSIVE MEMORY LOCATIONS. THIS IS SHOWN IN FIG. 3-4-5.



SINGLE BYTE INSTRUCTION


BYTE ONE
D7
D0
OPCODE
BYTE TWO
D7
D0
DATA OR ADDRESS

TWO BYTE INSTRUCTION


BYTE ONE
D7
D0
OPCODE
BYTE TWO
D7
D0
DATA
OR
ADDRESS
BYTE THREE
D7
D0

THREE BYTE INSTRUCTION

FIG. 3-4-5
INSTRUCTION & DATA FORMAT

THE EXACT INSTRUCTION FORMAT WILL DEPEND ON THE PARTICULAR OPERATION TO BE EXECUTED.

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IV. A SAMPLE PROGRAM. PROBLEM: 7+10=? THERE ARE THREE INSTRUCTIONS AND A DESCRIPTION OF WHAT THEY ARE. THIS IS SHOWN IN FIG. 3-4-6.

NAME	MNEMONIC	OPCODE	DESCRIPTION
LOAD ACCUMULATOR	LDA	10000110_2 OR 86_{16}	LOAD THE CONTENTS OF THE NEXT MEMORY LOCATION INTO THE ACCUMULATOR.
ADD	ADD	10001011_2 OR 86_{16}	ADD THE CONTENTS OF THE NEXT MEMORY LOCATION TO THE PRESENT CONTENTS OF THE ACCUMULATOR, THEN PLACE THE SUM IN THE ACCUMULATOR.
HALT	HLT	00111110_2 OR $3E_{16}$	STOP ALL OPERATIONS.

FIG. 3-4-6 INSTRUCTION USED IN PROGRAM

NAME--THE NAME OF THE INSTRUCTION
MNEMONIC--ABBREVIATION FOR EACH INSTRUCTION
OPCODE--THE BINARY NUMBER THAT THE COMPUTER AND PROGRAMMER USE TO REPRESENT THE INSTRUCTION
DESCRIPTION--DESCRIBE EXACTLY WHAT OPERATION IS PERFORMED

SINCE WE HAVE DECIDED TO ADD 7 TO 10 IN OUR ELEMENTARY PROGRAM AND PLACE THE SUM IN THE ACCUMULATOR, WE WILL PROCEED AS FOLLOWS:

A. LOAD 7 INTO THE ACCUMULATOR WITH THE LDA INSTRUCTION
B. ADD 10 TO THE ACCUMULATOR, USING THE ADD INSTRUCTION
C. STOP THE COMPUTER WITH THE HLT.

USING THE MNEMONICS AND THE DECIMAL REPRESENTATIONS OF THE NUMBERS TO BE ADDED, THE PROGRAM LOOKS LIKE THIS:

```
          LDA 7
          ADD 10
          HLT
```

BUT, THE BASIC MICROPROCESSOR CANNOT UNDERSTAND MNEMONICS OR DECIMAL NUMBERS. IT CAN INTERPRET BINARY NUMBERS AND NOTHING ELSE. THAT IS:

```
          LDA 7 ---10000110    00000111
          ADD 10 --10001011    00001010
   AND
          HLT   ---00111110
```

THE PROGRAM IN MEMORY RESEMBLES FIG. 3-4-7

NOTICE THAT EACH MEMORY LOCATION HAS TWO 8 BIT BINARY NUMBERS ASSOCIATED WITH IT. ONE IS ITS ADDRESS--THE OTHER IS ITS CONTENTS.

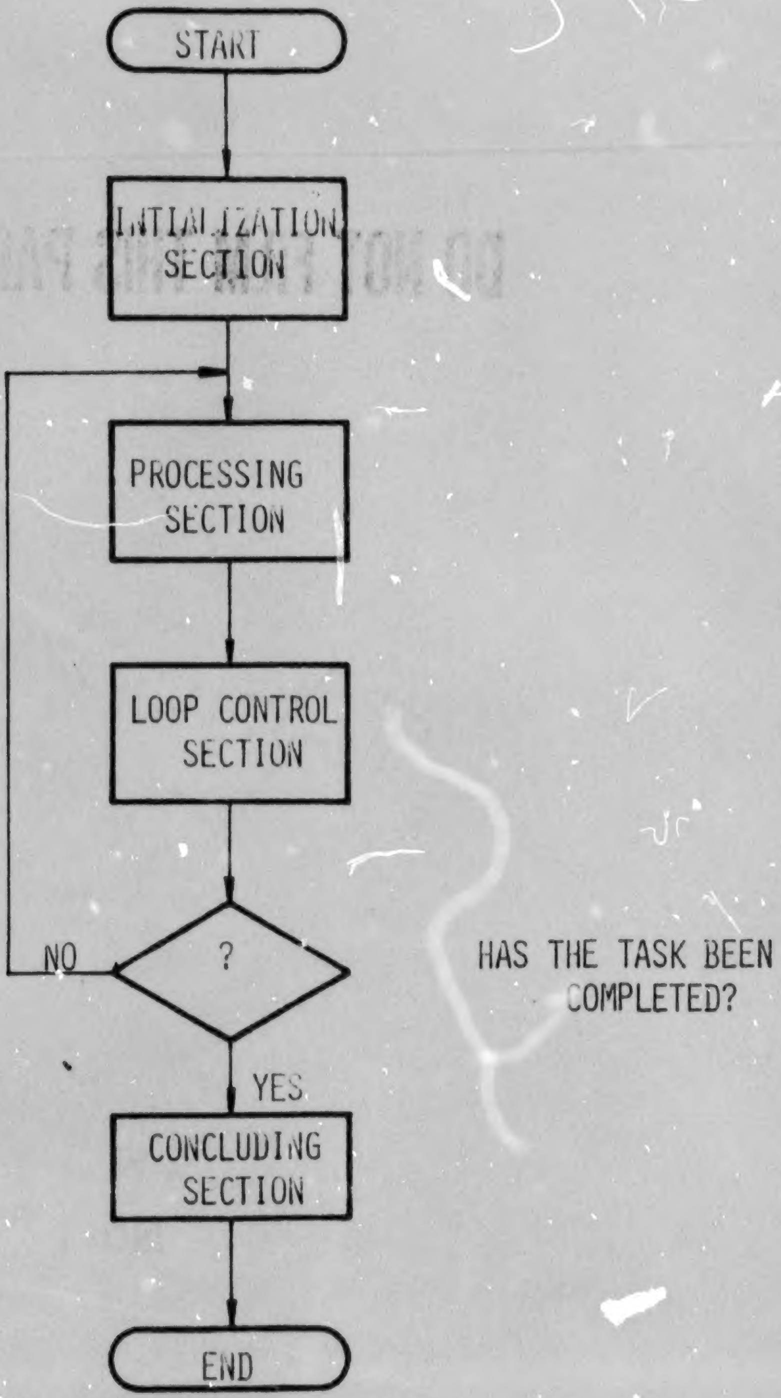
START
INITIALIZATION SECTION
PROCESSING SECTION
LOOP CONTROL SECTION
NO
?
HAS THE TASK BEEN COMPLETED?
YES
CONCLUDING SECTION
END

FIG. 3-4-7
THE PROGRAM IN MEMORY

V. ADDRESSING MODES

A. INHERENT OR IMPLIED ADDRESSING. IN SOME SINGLE-BYTE INSTRUCTIONS, THE OPERAND IS IMPLIED BY THE OPCODE ITSELF. FOR EXAMPLE, THE INCREMENT ACCUMULATOR INSTRUCTION. THE NUMBER THAT IS OPERATED UPON IS THE NUMBER IN THE ACCUMULATOR. THIS TYPE OF ADDRESSING WILL BE REFERRED TO AS EITHER IMPLIED ADDRESSING OR INHERENT ADDRESSING.

ADVANTAGES: REQUIRE LITTLE MEMORY SPACE.
REQUIRE A MINIMUM OF EXECUTION TIME.

B. IMMEDIATE ADDRESSING. IN THIS FORM OF ADDRESSING, THE INSTRUCTION CONTAINS THE DATA ITSELF. FOR EXAMPLE, ADD30_{10} REQUESTS THE ASSEMBLER TO GENERATE AN ADD INSTRUCTION WHICH WILL ADD THE VALUE 30_{10} TO ACCUMULATOR A.

C. DIRECT ADDRESSING. THIS FORM OF ADDRESSING USES THE SECOND BYTE OF THE INSTRUCTION TO IDENTIFY AN OPERAND PRESENT IN THE LOW 256_{10} WORDS OF MEMORY. THIS FORM OF ADDRESSING IS SPECIFIED THAT THE SECOND BYTE IS THE ADDRESS OF THE OPERAND. FOR EXAMPLE: --IN THE IMMEDIATE ADDRESSING MODE, IT MEANS LOAD 50_{10} INTO THE ACCUMULATOR. --IN THE DIRECT ADDRESSING MODE, IT MEANS LOAD THE NUMBER AT MEMORY LOCATION 50_{10} INTO THE ACCUMULATOR.

VI. PROGRAM EXAMPLE

A. ONE COMPLEMENT:

MEMORY ADDRESS (HEX)	MEMORY CONTENTS (HEX)	MNEMONICS/ DECIMAL CONTENTS	COMMENTS
00	96	LDAA	LOAD ACCUMULATOR WITH ADDRESS 64
01	40	64_{10}	
02	43	COMA	COMPLEMENT ACCUMULATOR A.
03	97	STAA	STORE ACCUMULATOR A. AT THIS ADDRESS
04	41	45_{10}	
05	E	HLT	STOP

B. 8 BIT ADDITION

MEMORY ADDRESS (HEX)	MEMORY CONTENTS (HEX)	MNEMONICS/ DECIMAL CONTENTS	COMMENTS
00	86	LDA	LOAD ACCUMULATOR WITH OPERAND
01	21	33_{10}	
02	8B	ADD	ADD TO ACCUMULATOR IMMEDIATELY
03	17	23_{10}	OPERAND
04	97	STA	STORE THE SUM
05	07	07	AT THIS ADDRESS
06	3E	HLT	STOP
07	--	--	----

VII. BRANCHING. THE PROGRAM WE DISCUSSED IN PREVIOUS UNIT. IN ALL "STRAIGHT LINE" PROGRAMS, THE INSTRUCTIONS WERE EXECUTED ONE AFTER ANOTHER IN THE ORDER IN WHICH THEY WERE WRITTEN. PROGRAMS OF THIS TYPE ARE EXTREMELY LIMITED BECAUSE THEY USE ONLY A FRACTION OF THE MICROPROCESSOR'S POWER. THE REAL POWER OF THE MICROPROCESSOR COMES FROM ITS ABILITY TO EXECUTE A SECTION OF A PROGRAM OVER AND OVER AGAIN. FOR EXAMPLE: TWO NUMBERS COULD BE MULTIPLIED BY REPEATED ADDITION. SAY, 7 x 5 WITH THE FOLLOWING PROGRAM:

ADD	CONTENTS	MNEMONICS	COMMENTS
00	96	LAD	LOAD DIRECT
01	0A		
02	9B	ADD	ADD DIRECT
03	0		
04	9B	ADD	ADD DIRECT
05	0A		
06	9B	ADD	ADD DIRECT
07	0A		
08	9B	ADD	ADD DIRECT
09	3F	HLT	
0A	07		

THIS TECHNIQUE IS VERY CRUDE FOR A NUMBER OF REASONS. IF THE TWO NUMBERS ARE LARGE, SUCH AS 98 AND 150, THE NUMBER OF ADD INSTRUCTIONS BECOMES EXCESSIVE. IN ADDITION, THE VALUES OF TWO NUMBERS TO BE MULTIPLIED ARE GENERALLY NOT KNOWN. THEREFORE, EVEN IF WE WERE WILLING TO WRITE ENOUGH ADD INSTRUCTIONS, WE SIMPLY WOULD NOT KNOW HOW MANY TO WRITE. SO, SOME BETTER TECHNIQUE MUST BE AVAILABLE.

A. LOOPING. THE PROGRAM LOP IS THE BASIC STRUCTURE THAT FORCES THE CPU TO REPEAT A SEQUENCE OF INSTRUCTIONS. THE LOOPS HAVE FOUR SECTIONS. (THIS IS SHOWN IN FIG. 3-4-8)

1. THE INTIALIZATION SECTION, WHICH ESTABLISHES THE STARTING VALUES OF COUNTERS, ADDRESSES, REGISTERS (POINTERS); AND OTHER VARIABLES.

2. THE PROCESSING SECTION, WHERE THE ACTUAL DATA MANIPULATION OCCURS. THIS IS THE SECTION THAT DOES THE WORK.
3. THE LOOP CONTROL SECTION, WHICH UPDATES COUNTERS AND POINTERS FOR THE NEXT ITERATION.
4. THE CONCLUDING SECTION, WHICH ANALYZES AND STORES THE RESULTS.

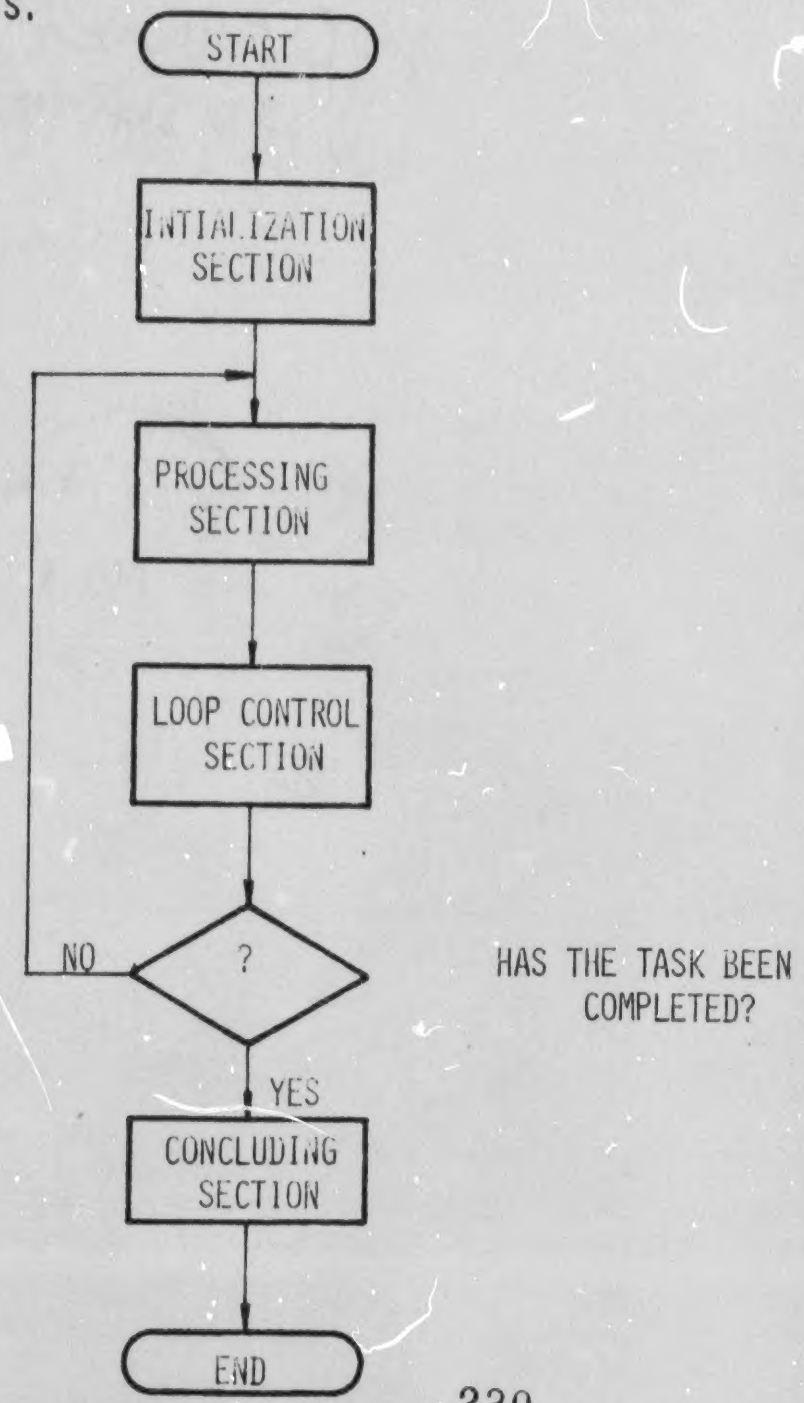
START
INITIALIZATION SECTION
PROCESSING SECTION
LOOP CONTROL SECTION
NO
?
HAS THE TASK BEEN COMPLETED?
YES
CONCLUDING SECTION
END

FIG. 3-4-8 SEQUENCE OF INSTRUCTIONS

NOTE THAT THE COMPUTER PERFORMS SECTION 1 AND 4 ONCE, WHILE IT MAY PERFORM SECTIONS 2 AND 3 MANY TIMES. THUS, THE EXECUTION TIME OF THE LOOP WILL MAINLY DEPEND ON THE EXECUTION TIME OF SECTION 2 AND 3. YOU WILL WANT SECTION 2 AND 3 TO EXECUTE AS QUICKLY AS POSSIBLE; DO NOT WORRY ABOUT THE EXECUTION TIME OF SECTION 1 AND 4.

B. RELATIVE ADDRESSING. AS WE DISCUSSED BEFORE, IN THE IMMEDIATE ADDRESSING MODE, NO ADDRESS IS SPECIFIED. THE DATA IS ASSUMED TO BE THE BYTE FOLLOWING ONE OPCODE. IN DIRECT ADDRESSING MODE, AN ADDRESS IS GIVEN. THE DATA IS ASSUMED TO BE AT THAT ADDRESS. BRANCH INSTRUCTIONS ARE SOMEWHAT DIFFERENT FROM THAT. THE BRANCH INSTRUCTION HAS AN ADDRESS ASSOCIATED WITH IT, THE ADDRESS DOES NOT INDICATE THE LOCATION OF DATA. INSTEAD, THE INSTRUCTION THAT IS TO BE EXECUTED. ALL BRANCH INSTRUCTIONS ARE TWO BYTE INSTRUCTIONS; THIS IS SHOWN IN FIG. 3-4-9.

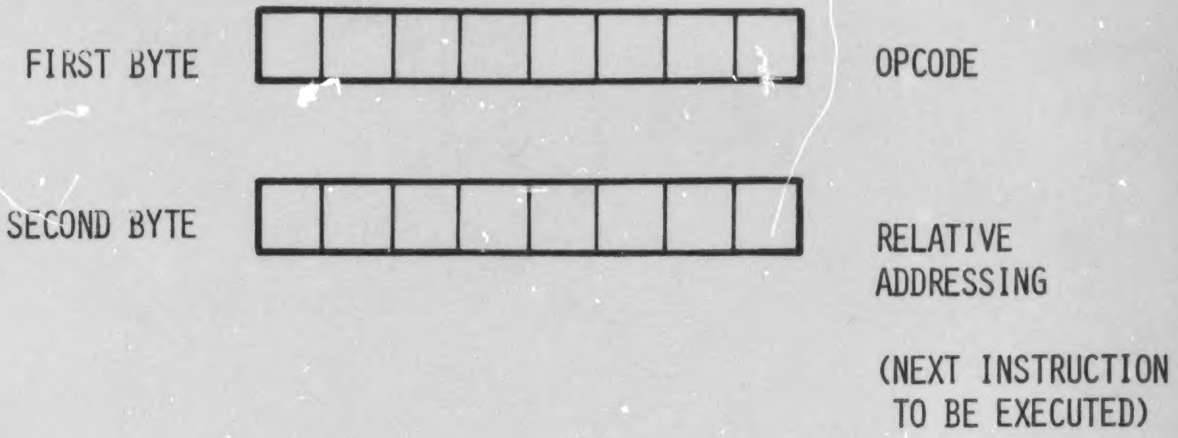

FIG. 3-4-9
FORMAT OF THE BRANCH INSTRUCTION

ADDRESS (HEX)	CONTENTS (HEX)	MNEMONICS	
18	20	BRA	
19	?	? 09	
1A	--	--	ORIGINATING ADDRESS
1B	--	--	
1C	--	--	
1D	--	--	
1E	--	--	
1F	--	--	
20	--	--	
21	--	--	
22	--	--	
23	--	--	DESTINATION ADDRESS
24	--	--	

$$\begin{array}{rrl} & 00100011_2 & 23_{16} \\ - & 00011010_2 & 1A_{16} \\ \hline & 00001001_2 & 09_{16} \text{ ------RELATIVE ADDRESS} \end{array}$$

FIG. 3-4-11

A BACKWARD BRANCH IS USED WHEN A PART OF THE PROGRAM IS TO BE REPEATED. THE DIFFERENCE OF THE BRANCHING BACKWARD AND FORWARD IS THAT THE BRANCHING BACKWARD IS USING A NEGATIVE NUMBER AS THE RELATIVE ADDRESS.

PROGRAM 3.

ADDRESS (HEX)	CONTENTS (HEX)	MNEMONICS
56	--	
57	--	
58	--	PROGRAM WILL
59	--	BRANCH TO
5A	--	HERE.
5B	--	
5C	--	
5D	20	BRA
5E	F9	F9
5F	--	
60	--	
61	--	
62	--	

FIG. 3-4-12

C. CONDITIONAL BRANCHING. THE BRANCH INSTRUCTION ALLOWS THE MICROPROCESSOR UNIT TO JUMP FORWARD OVER A BLOCK OF DATA OR OVER A PORTION OF A PROGRAM. IT ALSO ALLOWS THE MPU TO JUMP BACKWARDS SO A GROUP OF INSTRUCTIONS CAN BE REPEATED. BY FAR, WE HAVE BEEN DISCUSSING THE UNCONDITIONED BRANCH INSTRUCTION. THERE ARE OTHER TYPES OF BRANCH INSTRUCTIONS THAT GREATLY EXPAND THE VERSATILITY OF THE MPU. THESE ARE CALLED CONDITIONAL BRANCH INSTRUCTIONS. THESE INSTRUCTIONS CAUSE A BRANCH ONLY IF SOME SPECIFIED CONDITION IS MET. THERE IS A PART OF A PROGRAM THAT USES THE BRANCH MINUS (BMI) INSTRUCTION; THIS IS SHOWN IN FIG. 3-4-13.

ADDRESS (HEX)	CONTENTS (HEX)	MENMONICS (HEX)	COMMENTS
95	96	LDA	LOAD ACCUMULATOR DIRECT
96	BO	BO	WITH CONTENTS OF THIS ADDRESS
97	90	SUB	SUBTRACT
98	B1	B1	THE CONTENTS OF THIS ADDRESS
99	2B	BMI	IF RESULT IS MINUS,
9A	03	03	BRANCH TO 97
9B	97	STA	IF RESULT IS MINUS, STORE
9C	B2	B2	AT THIS ADDRESS
9D	3E	HLT	THEN HALT
9E	97	STA	IF RESULT IS MINUS, STORE
9F	B3	B3	IT AT THIS ADDRESS
90	3E	HLT	THEN HALT

FIG. 3-4-13 PROGRAM USES BMI INSTRUCTION

AS MENTIONED BEFORE, A CONDITIONAL BRANCH INSTRUCTION CAUSES A PROGRAM BRANCH ONLY IF SOME SPECIFIED CONDITION IS MET. SOME COMMON CONDITIONS ARE:

1. DID A PREVIOUS OPERATION RESULT IN A NEGATIVE NUMBER IN THE ACCUMULATOR?
2. DID A PREVIOUS OPERATION RESULT IN ZERO IN THE ACCUMULATOR?
3. DID A PREVIOUS OPERATION RESULT IN A CARRY FROM BIT 7 OF THE ACCUMULATOR?

I. ARITHMETIC PROBLEM. MOST ARITHMETIC IN MICROPROCESSOR APPLICATIONS CONSISTS OF MULTIPLE-WORD BINARY OR DECIMAL MANIPULATIONS. AN ARITHMETIC IS A STEP BY STEP PROCEDURE FOR DOING A PARTICULAR JOB. IT GENERALLY INVOLVES DOING A COMPLEX TASK BY STRINGING TOGETHER A SERIES OF SIMPLE STEPS.

A. MULTIPLYING BY REPEATED ADDITION. MOST MICROPROCESSORS DO NOT HAVE HARDWARE MULTIPLY CAPABILITIES. THAT IS, THEY DO NOT HAVE A MULTIPLICATION CIRCUIT NOR A MULTIPLY INSTRUCTION. ONE PROCEDURE FOR DOING THIS IS ADDING THE MULTIPLICAND TO ITSELF THE NUMBER OF TIMES INDICATED BY THE MULTIPLIER. SECOND, YOU MUST KNOW THE VALUE OF THE MULTIPLIER SO THAT YOU KNOW HOW MANY ADD INSTRUCTIONS TO INCLUDE. A BETTER APPROACH IS TO USE A PROGRAM LOOP THAT WILL MULTIPLY TWO NUMBERS BY REPEATED ADDITION. FIG. 3-4-14 IS A FLOWCHART THAT ILLUSTRATES THE MULTIPLYING BY REPEATED ADDITION.

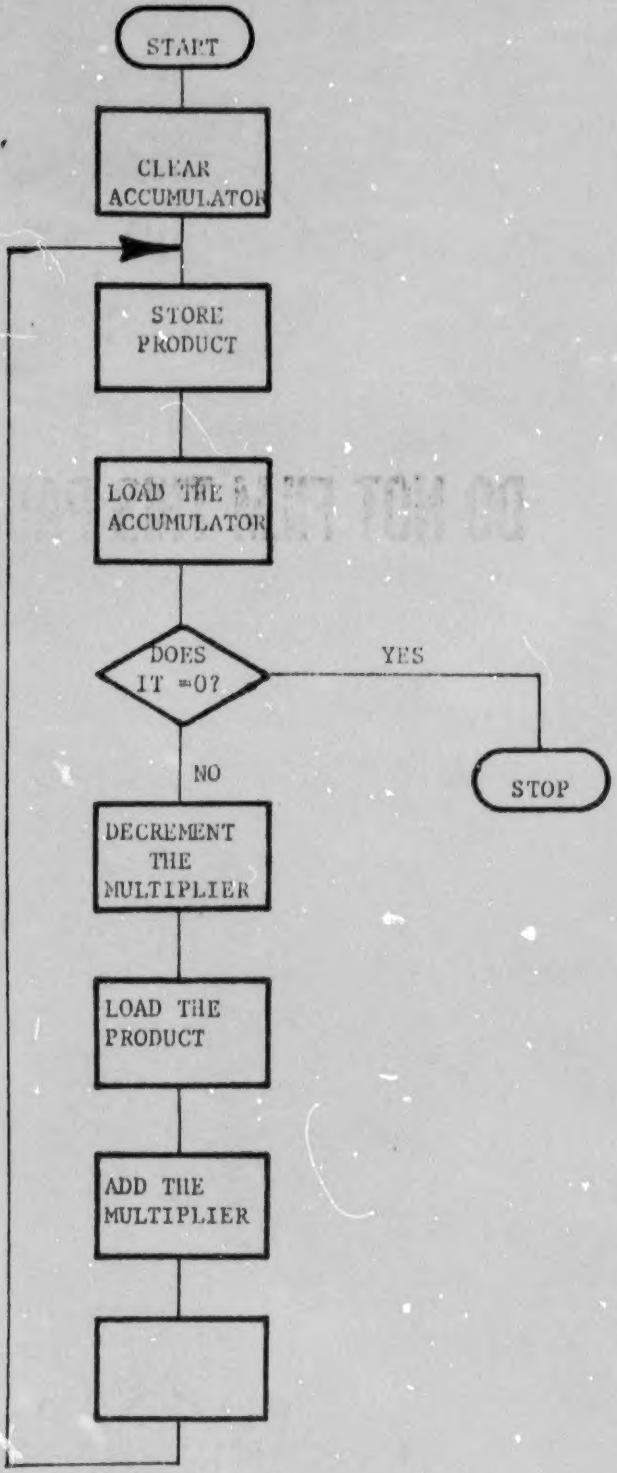
START
CLEAR ACCUMULATOR
STORE PRODUCT
LOAD THE ACCUMULATOR
DOES IT =0?
YES
STOP
NO
DECREMENT THE MULTIPLIER
LOAD THE PRODUCT
ADD THE MULTIPLIER

FIG. 3-4-14

MULTIPLYING BY REPEATED ADDITION

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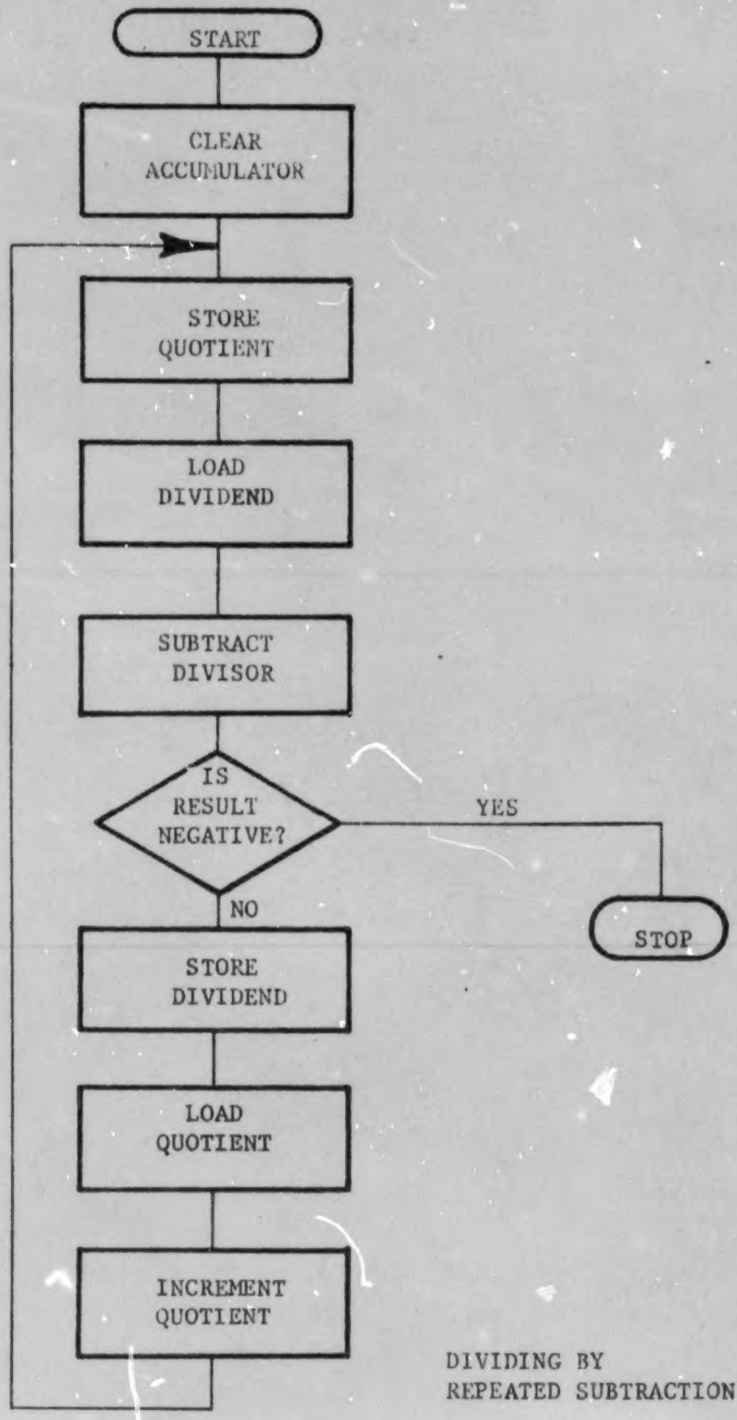
EXAMPLE:

ADDRESS (HEX)	CONTENTS (HEX)	MNEMONICS (HEX)	COMMENTS
00	4F	CLRA	CLEAR THE ACCUMULATOR
01	97	STA	STORE THE PRODUCT
02	13	13	IN LOCATION 13
03	96	LDA	LOAD THE ACCUMULATOR WITH THE
04	12	12	MULTIPLIER FROM LOCATION 12
05	27	BEQ	IF THE MULTIPLIER IS EQUAL TO ZERO
06	09	09	BRANCH DOWN TO THE HALT INSTRUCTION
07	4A	DECA	OTHERWISE, DECREMENT THE MULTIPLIER
08	97	STA	STORE THE NEW VALUE OF THE
09	12	12	MULTIPLIER BACK IN LOCATION 12
0A	96	LDA	LOAD THE ACCUMULATOR WITH THE
0B	13	13	PRODUCT FROM LOCATION 13
0C	9B	ADD	ADD
0D	11	11	THE MULTIPLCANT TO THE PRODUCT
0E	20	BRA	BRANCH BACK TO INSTRUCTION
0F	F1	F1	IN LOCATION 01
10	3E	HLT	HALT
11	05	05	MULTIPLICANT
12	03	03	MULTIPLIER
13	--	--	PRODUCT

II. DIVIDING BY REPEATED SUBTRACTION.

A. FLOWCHART, FIG. 3-4-14.


START
CLEAR ACCUMULATOR
STORE QUOTIENT
LOAD DIVIDEND
SUBTRACT DIVISOR
IS RESULT NEGATIVE?
YES
STOP
NO
STORE DIVIDEND
LOAD QUOTIENT
INCREMENT QUOTIENT

DIVIDING BY
REPEATED SUBTRACTION

B. EXAMPLE:

ADDRESS (HEX)	CONTENTS (HEX)	MNEMONICS (HEX)	COMMENTS
00	4F	CLRA	CLEAR THE ACCUMULATOR
01	97	STA	STORE IN THE QUOTIENT WHICH
02	13	13	IS AT ADDRESS LOCATION 13_{16}
03	96	LDA	LOAD THE ACCUMULATOR WITH
04	11	11	THE DIVIDEND FROM LOCATION 11_{16}
05	90	SUB	SUBTRACT THE
06	12	12	DIVISOR FROM THE DIVIDEND
07	2B	BMI	IF THE DIFFERENCE IS NEGATIVE
08	07	07	BRANCH DOWN TO HALT
09	97	STA	OTHERWISE, STORE THE DIFFERENCE
0A	11	11	BACK IN LOCATION 11_{16}
0B	96	LDA	LOAD THE ACCUMULATOR WITH THE
0C	13	13	QUOTIENT
0D	4C	INCA	INCREMENT THE QUOTIENT BY ONE
0E	20	BRA	BRANCH BACK TO INSTRUCTION
0F	F1	F1	IN LOCATION 01.
10	3E	HLT	HALT
11	2F	2F	DIVIDEND(47_{10})
12	0F	0F	DIVISOR(15_{10})
13	--	--	QUOTIENT

LESSON PLAN #4

UNIT 3--INTRODUCTION TO PROGRAMMING

ASSIGNMENT SHEET 1

AFTER READING THE INFORMATION SHEET PROVIDED, COMPLETE THE FOLLOWING QUESTIONS IN WRITING OR AS REQUESTED BY YOUR INSTRUCTOR.

1. DRAW A DIAGRAM TO EXPLAIN THE THREE TYPES OF BUSES THAT ARE USED IN A MICROCOMPUTER.

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2. WHAT IS THE FUNCTION OF THE ARITHMETIC LOGICAL UNIT OF THE MICROCOMPUTER?

3. WHAT DOES RAM AND ROM MEAN? AND WHAT IS THE DIFFERENCE BETWEEN THE TWO?

4. WHAT ARE THE ADVANTAGES OF INHERENT ADDRESSING?

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5. IF WE WISH TO BRANCH TO THE INSTRUCTION AT ADDRESS 12_{16}, THE OPCODE FOR THE BRANCH INSTRUCTION IS ATE ADDRESS OA_{16}, WHAT RELATIVE ADDRESS IS REQUIRED AT THE LOCATION OB_{18} IN ORDER TO IMPLEMENT THIS BRANCH?

ADDRESS (HEX)	CONTENTS (HEX)	MNEMONICS
OA	20	BRA
OB	?	?
OC	--	--
OD	--	--
OE	--	--
OF	--	--
10	--	--
11	--	--
12	--	--
13	--	--
14	--	--
15	--	--

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SYLLABUS SHEET FOR LESSON 1
ROBOT SERVICE AND REPAIR

UNIT #3 ROBOT CONTROL SYSTEM

BASIC CONTROL SYSTEM OF A ROBOT

LESSON OBJECTIVE--UPON COMPLETION OF THIS LESSON, THE STUDENT SHOULD BE ABLE TO:

TEACHING AIDS:

1. H3-1-1 SYLLABUS
2. T3-1-1 CONTROL SYSTEM
3. T3-1-2 A POTENTIAL TRANSDUCER
4. T3-1-3 TRANSISTOR
5. T3-1-4 SYNCHRO-TRANSMITTER
6. T3-1-5 SYNCHRO-RECEIVER
7. T3-1-6 DIFFERENTIAL SYNCHRO-TRANSMITTER
8. T3-1-7 DIFFERENTIAL SYNCHRO-RECEIVER
9. T3-1-8 CONTROL TRANSFORMER

INFORMATIONAL ASSIGNMENTS:

1. IS3-1-1 TYPES OF SYSTEMS
2. IS3-1-2 FEEDBACK AND TRANSDUCER
3. IS3-1-3 OTHER TRANSDUCERS
4. IS3-1-4 SYNCHRO-SYSTEM

ANSWER QUESTIONS FOUND ON ASSIGNMENT SHEETS

1. AS3-1-1 BASIC CONTROL SYSTEM OF A ROBOT

REFERENCES:

GROOVER, M.P. AUTOMATION, PRODUCTION SYSTEMS, AND CAM. PRENTICE HALL, INC., N.J., 1980.

SAFFORD, E.L. THE COMPLETE HANDBOOK OF ROBOTICS, TAB BOOKS, 1978.

STEP 1-INTRODUCTION FOR PREPARATION OF THE STUDENT:

MUCH OF THE INFORMATION USED IN INDUSTRIAL CONTROL AND ROBOTICS IS OBTAINED IN ANALOG FORM AND USED OR DISPLAYED IN THE SAME ANALOG FORM. SYNCHRO-SYSTEMS AND SERVO MECHANISMS ARE ONE OF THE PRIMARY METHODS OF ACQUIRING ANALOG INFORMATION, CONVERTING IT TO ELECTRICAL INFORMATION, AND THEN USING THE ELECTRICAL SIGNALS TO PRODUCE AN ANALOG DISPLAY OR CONTROL FUNCTION.

IN THIS UNIT, THE STUDENT WILL LEARN THE CONTROL SYSTEM AND THE BASIC SYNCHRO-SYSTEM USED IN DISPLAY AND CONTROL ANALOG FUNCTIONS.

LESSON SUMMARY AND REVIEW:

1. WHAT IS AN OPEN-LOOP SYSTEM?

2. WHAT IS THE DIFFERENCE BETWEEN AN OPEN-LOOP SYSTEM AND A CLOSED-LOOP SYSTEM?

3. WHAT IS THE MAIN PURPOSE OF A TRANSDUCER?

4. HOW MANY TYPES OF SYNCHRO-DEVICES ARE USED IN A SYNCHRO-SYSTEM?

TYPES OF A SYSTEM

ALL CONTROL SYSTEMS MAY BE CONSIDERED TO BE A COMBINATION OF ELEMENTS WITH THE PURPOSE OF CONTROLLING A QUANTITY OF INTEREST IN A MACHINE MECHANISM OR A PLANT. THERE ARE TWO DIFFERENT SYSTEMS USED TODAY: THE OPEN-LOOP SYSTEM AND THE CLOSED-LOOP SYSTEM.

1. OPEN LOOP SYSTEM.

   ANY PHYSICAL SYSTEM THE INPUT DOES NOT DEPEND UPON WHAT HAPPENS AT THE OUTPUT OF THE SYSTEM. LIKE YOUR WASHING MACHINE, FOR EXAMPLE, YOU PUT IN YOUR DIRTY CLOTHES AND SET THE MACHINE TO PERFORM CERTAIN OPERATIONS. IT WASHES, RINSES, AND SPIN DRIES, THEN IT STOPS. BUT IT NEVER EXAMINES THE CLOTHES TO SEE WHETHER THEY ARE CLEAN OR NOT. IT DID ITS ASSIGNED TASKS IN THE ORDER YOU COMMANDED IT TO DO THEM, THEN IT STOPPED OPERATING. ITS INPUT DID NOT DEPEND ON ITS OUTPUT. SEE T3-1-1 (A).

2. CLOSED LOOP SYSTEM.

   A CLOSED-LOOP SYSTEM IS ONE IN WHICH THE INPUT DOES DEPEND ON WHAT THE OUTPUT IS DOING. IT HAS A FEATURE OF FEEDBACK THAT THE INPUT IS DETERMINED IN WHOLE OR IN PART BY THE OUTPUT. FOR EXAMPLE, IF YOU SET THE THERMOSTAT IN YOUR HOME FOR A TEMPERATURE OF 70 DEGREES, THE HEATING (OR COOLING) SYSTEM WILL OPERATE UNTIL THE INPUT (THE THERMOSTAT) RECOGNIZES THAT THE OUTPUT (THE HEAT OR COLD AIR) HAS ADJUSTED THE ROOM TEMPERATURE TO THE DESIRED SETTING. ALL AUTOMATIC HEATING AND COOLING SYSTEMS ARE EXAMPLES OF CLOSED-LOOP SYSTEMS. SEE T3-1-1, (B). THESE KIND OF SYSTEMS ARE CAPABLE OF BEING DESIGNED TO BE SELF-CORRECTING AND TO ADJUST THEIR OUTPUTS TO REDUCE THE AMOUNT OF AN ERROR SIGNAL.

3. DIFFERENCES IN THE SYSTEM.

   THE FUNDAMENTAL DIFFERENCE IN THE TWO SYSTEMS IS THAT THE CLOSED-LOOP SYSTEM HAS FEEDBACK INFORMATION FROM THE OUTPUT. WHATEVER THE OUTPUT MAY BE, PERHAPS MOTION, LIGHT, OR HEAT, A SIGNAL PROPORTIONAL TO THIS IS SENT TO A COMPARATOR, WHICH ESSENTIALLY COMPARES WHAT THE OUTPUT IS DOING TO WHAT IT WAS COMMANDED TO DO. WHEN THE OUTPUT HAS DONE EXACTLY WHAT IT WAS COMMANDED , THE DIFFERENCE IN INPUT SIGNAL AND FEEDBACK SIGNAL

WILL BE ZERO, AND THE COMMANDS TO THE CONTROL AMPLIFIER FOR ACTION WILL STOP.

CLOSED-LOOP SYSTEMS POSSESS SEVERAL SPECIAL ATTRIBUTES AS COMPARED TO OPEN-LOOP SYSTEMS:

A. IMPROVE ACCURACY.
B. INCREASE IN THE BANDWIDTH OF THE SYSTEM, THEREBY YEILDING IMPROVED PERFORMANCE.
C. DECREASE THE EFFECT OF DISTORTION AND NONLINEARITIES.

FEEDBACK AND TRANSDUCER

1. FEEDBACK.

A FEEDBACK IS ALWAYS OF AN OPPOSITE POLARITY TO THE INPUT COMMAND SIGNAL NO MATTER HOW THE OUTPUT MOVES. IT IS TO CONNECT AN OUTPUT TRANSDUCER TO PROVIDE FEEDBACK, REINFORCING THE INPUT COMMAND.

THERE ARE SEVERAL DIFFERENT KINDS OF FEEDBACK SYSTEMS TO BE USED IN A CONTROL SYSTEM. THE MOST POPULAR ONE IS THE ELECTRICAL SIGNAL FEEDBACK SYSTEM. THE ELECTRICAL FEEDBACK SIGNAL AND ELECTRICAL INPUT SIGNAL CONSTITUTE THE BEST AND THE SIMPLEST WAYS FOR US TO GET THE REQUIRED CONDITIONS FOR A GOOD ROBOT DESIGN.

IF THE INPUT IS AN ELECTRICAL SIGNAL AND THE OUTPUT IS AN ELECTRICAL SIGNAL, WE CAN THEN COMPARE ELECTRICAL SIGNALS IN A SMALL, BUT EFFECTIVE, INTEGRATED CIRCUIT: THE COMPARISON AMPLIFIER. THIS CAN BE DONE WITH EASE AND DEPENDABILITY, BUT WE CANNOT DIRECTLY COMPARE A LIGHT OUTPUT OR A MECHANICAL MOTION OUTPUT TO AN ELECTRICAL SIGNAL. WE MUST HAVE RELATED ITEMS TO MAKE A COMPARISON OF THEIR SIZE, WEIGHT, SHAPE, PHASE, OR MAGNITUDE. SO, WE MUST CONVERT ALL THESE OTHER QUANTITIES INTO ELECTRICAL SIGNALS THROUGH THE USE OF TRANSDUCERS.

2. TRANSDUCER.

IN MOST AUTOMATED SYSTEMS, A TRANSDUCER IS REQUIRED. THE SIMPLEST EXAMPLE OF A TRANSDUCER IS PROBABLY THE POTENTIOMETER, AS SHOWN IN T3-1-2. IT CAN GIVE A PLUS OR MINUS OUTPUT SIGNAL AT A LEVEL FROM ZERO (CENTER POSITION) TO THE MAXIMUM OF THE APPLIED VOLTAGE. IN BETWEEN ZERO AND THE MAXIMUM, WE HAVE A PROPORTIONAL (TO THE AMOUNT OF ROTATION) VOLTAGE FOR EACH POSITION OF THE POTENTIOMETER WIPER. EACH POSITION OF THE WIPER HAS BEEN ROTATED AND IN WHAT DIRECTION, IF WE KNOW THE ANGULAR SCALE IN VOLTS PER DEGREE, THE FUNCTION OF A CONTROL AMPLIFIER IS EXACTLY FOR THIS.

SYNCHRO-SYSTEM

A SYNCHRO-SYSTEM EMPLOYS TWO OR MORE "SELF SYNCHRONIZING" DEVICES WHICH ARE SIMILAR IN APPEARANCE TO SMALL ELECTRIC MOTORS. THESE DEVICES CONVERT THE ANGULAR POSITION OF A MECHANICAL SHAFT TO EQUIVALENT ELECTRICAL SIGNALS, WHICH TRANSMIT THE ELECTRICAL SIGNALS OVER WIRES AND ULTIMATELY CONVERT THE ELECTRICAL SIGNALS BACK INTO MECHANICAL FORM, SAME AS THE TRANSMITTED ANGULAR POSITION.

SYNCHROS ARE USED EXTENSIVELY IN REMOTE, INDICATING SYSTEMS. IT IS ABOUT ONE INCH IN DIAMETER AND TWO TO THREE INCHES IN LENGTH. IT IS JUST A SMALL TRANSFORMER USED ENTIRELY TO GIVE A FEEDBACK SIGNAL. ANY INFORMATION THAT IS DISPLAYED ON A DIAL CAN USUALLY BE TRANSMITTED TO A REMOTE INDICATOR, USING A SYNCHRO-SYSTEM.

WHEN INFORMATION IS IN THE FORM OF SHAFT POSITION, IT IS EXPRESSED IN TERMS OF THE ANGLE BETWEEN ACTUAL SHAFT POSITION AND SOME ZERO OR REFERENCE POSITION. THIS ANGULAR POSITION CAN BE CONVERTED BY A SYNCHRO TO A SET OF THREE VOLTAGES CALLED SYNCHRO-DATA. SYNCHRO-DATA CAN EASILY BE TRANSMITTED TO A REMOTE POINT, WHERE A SECOND SYNCHRO (CALLED A RECEIVER) IS USED TO SET ANOTHER SHAFT TO A CORRESPONDING ANGULAR POSITION. THE RECEIVER PROVIDES ONLY A VOLTAGE OUTPUT, WHICH DRIVES A SERVO-SYSTEM. USUALLY, THERE IS NO POWER GAIN IN A PURE SYNCHRO-SYSTEM. DISREGARDING FRICTION LOSSES, THE MECHANICAL POWER OUTPUT OF THE RECEIVER IS EQUAL TO THE MECHANICAL POWER INPUT TO THE TRANSMITTER. THERE ARE FIVE BASIC TYPES OF SYNCHRO-DEVICES:

1. TRANSMITTER - IS SOMETIMES REFERRED TO AS A SYNCHRO-GENERATOR. THE ROTOR 1) CONSISTS OF A SINGLE WINDING, AND THE STATOR 2) IS MADE UP OF THREE WINDINGS DISPLACED AT 120°, AS SHOWN IN T3-1-4. THE ROTOR IS EXCITED BY AN AC SOURCE AND IS USUALLY COUPLED DIRECTLY OR INDIRECTLY THROUGH GEARS TO A CONTROLLING SHAFT.

   THE CONTROLLING SHAFT REPRESENTS SOME ANGULAR POSITION TO BE TRANSMITTED. THIS ANGULAR POSITION COULD BE REPRESENTATIVE OF A TEMPERATURE OR PRESSURE GAUGE SETTING, OR THE LATERAL POSITION OF A ROBOT. IN SOME CASES, THE CONTROL SHAFT IS POSITIONED BY A PERSON DIALING IN A SPECIFIC SETTING, TO CONTROL SOME REMOTE DEVICE OR FUNCTION.

2. SYNCHRO-RECEIVER - IS SOMETIMES CALLED A SYNCHRO-MOTOR. IT IS SIMILAR ELECTRICALLY TO THE SYNCHRO-TRANSMITTER. UNLIKE THE SYNCHRO-TRANSMITTER, THE ROTOR OF THE SYNCHRO-RECEIVER IS FREE TO TURN AND USUALLY DRIVES A LIGHT LOAD, SUCH AS A DIAL, POINTER, OR SOME OTHER INDICATING DEVICE. THE DRIVE IS ACCOMPLISHED DIRECTLY, OR THROUGH A LIGHT GEAR TRAIN ASSEMBLY. THE ANGULAR POSITION THAT THE ROTOR ASSUMES IS DEPENDENT UPON THE STATOR VOLTAGE RECEIVED FROM THE SYNCHRO-TRANSMITTER, AS SHOWN IN T3-1-5.
3. DIFFERENTIAL SYNCHRO-TRANSMITTER - AS SHOWN IN T3-1-6, THE DIFFERENTIAL SYNCHRO-TRANSMITTER RESEMBLES THE REGULAR SYNCHRO-TRANSMITTER, IN WHICH THE ROTOR IS MECHANICALLY POSITIONED AND THE STATOR IS SIMILAR. HOWEVER, THE ROTOR OF THE DIFFERENTIAL TRANSMITTER CONTAINS THREE SEPARATE WINDINGS WHICH ARE DISPLACED 120°. THE MAIN PURPOSE OF THE DIFFERENTIAL TRANSMITTERS IS USED TO CORRECT FOR ERROR EXISTING IN VARIOUS PARTS OF THE SYNCHRO-SYSTEM.
4. DIFFERENTIAL SYNCHRO-RECEIVER - IS SIMILAR IN DESIGN TO THE DIFFERENTIAL TRANSMITTER EXCEPT THAT THE ROTOR IS FREE TO TURN, AS SHOWN IN T3-1-7. IT IS USED WHEN IT BECOMES NECESSARY TO ADD OR SUBTRACT TWO ANGULAR TRANSMITTERS. ITS ROTOR WOULD ASSUME A POSITION CORRESPONDING TO THE ANGULAR SUM OR DIFFERENCE OF THE TRANSMITTER ROTOR POSITION.
5. CONTROL TRANSFORMER - AS SHOWN IN T3-1-8, A CONTROL TRANSFORMER IS USED TO INDICATE ANGULAR POSITION WHEN YOU WANT TO OBTAIN A VOLTAGE OUTPUT ONLY. IT IS SIMILAR TO THE SYNCHRO-RECEIVER, EXCEPT THAT THE WINDINGS OF THE CONTROL TRANSFORMER HAVE A HIGHER IMPEDENCE AND ALSO, ITS ROTOR IS NOT FREE TO TURN. SO, VOLTAGES FROM THE SYNCHRO-TRANSMITTER PRODUCE A VOLTAGE IN THE ROTOR OF THE CONTROL TRANSFORMER, WHICH IS A REPRESENTATIVE OF THE ANGULAR DISPLACEMENT OF THE TRANSMITTER ROTOR.

OTHER TRANSDUCERS

AS WE MENTIONED BEFORE, THE PRESSURE FEEDBACK SIGNALS ARE NEEDED TO ADJUST A HAND GRIP. WE ALSO MENTIONED VARIOUS TYPES AND DISCUSSED HOW THEY CAN BE USED. WE CONSIDER THE SIGNALS OUT OF THESE ELEMENTS AS FEEDBACK SIGNALS, WHICH WILL BE COMPARED TO A DEFINITE INPUT COMMAND. THIS WILL, IN TURN, ORIGINATE IN THE ROBOT OR FROM AN EXTERNALLY CREATED SIGNAL, WHICH YOU SEND THE ROBOT. THE PIEZO-ELECTRIC TRANSDUCER WILL GIVE A SIGNAL WHEN BENT OR TWISTED. BECAUSE OF THE CIRCUIT COMPLEXITY, WE WON'T ELABORATE ON IT HERE. THE STRAIN GAUGE IS MORE TO OUR IMMEDIATE CONCERN. IT CAN BE AN ELEMENT IN A BALANCE BRIDGE, AS SHOWN IN T3-1-3. HERE, WE ARE USING A TRANSISTOR FOR THE ELEMENT OF THE BALANCING PART OF THE BRIDGE.

NOTE HOW THE TWO ELEMENTS, THE STRAIN GAUGE AND THE TRANSISTOR, TAKE THE PLACE OF THE TWO HALVES OF THE POTENTIOMETER, SHOWN IN T3-1-2. IF A COMMAND TO "CLOSE FINGERS" IS SENT TO THE ROBOT, THE SIGNAL COULD OPERATE THE TRANSISTOR OF T3-1-3, CHANGE ITS RESISTANCE AND CAUSE THE BRIDGE TO UNBALANCE. THIS COULD CREATE A SIGNAL AT THE OUTPUT WITH A POLARITY ACCORDING TO WHETHER THE COMMAND CAUSES THE TRANSISTOR TO INCREASE OR DECREASE ITS RESISTANCE. SUPPOSE THAT THE FINGERS CLOSE AND THAT THEY CONTINUE TO CLOSE UNTIL THE STRAIN GAUGE IS DISTORTED ENOUGH SO THAT THE RESISTANCE PRESENTED BY IT ALSO EITHER INCREASE OR DECREASE ACCORDING TO HOW IT WAS PHYSICALLY STRAINED. IN THIS PROCESS, THE VOLTAGE ACROSS IT CHANGES UNTIL THIS NEW VALUE OF RESISTANCE EQUALS THE RESISTANCE OF THE TRANSISTOR. THE BRIDGE IS AGAIN BALANCED, THE OUTPUT IS ZERO, THE HAND STOPS CLOSING, AND DOES NOW EXERT AN ADDITIONAL PRESSURE ON WHATEVER IT IS GRASPING. THIS IS ONE KIND OF FORCE FEEDBACK OF A CONTROL SYSTEM; OTHER TYPES OF FEEDBACK MAY ALSO BE PRESENT.

OF COURSE, WHEN THE INTERNAL OR EXTERNAL COMMAND TO THE TRANSISTOR CHANGES, PERHAPS TO COMMAND THE HAND TO RELEASE THE OBJECT, THE RESISTANCE OF THE TRANSISTOR AGAIN CHANGES. THE HANDS MOTOR, THEN RECEIVING AN OPPOSITE POLARITY SIGNAL FROM THE OUTPUT OF THE BRIDGE, MUST RELEASE PRESSURE, CAUSING THE STRAIN GAUGE TO RELAX BACK TO ITS ORIGINAL SHAPE, WHICH WILL THEN REBALANCE THE BRIDGE AND STOP THE HAND'S GRASPING ACTION. THE MOVEMENT OF THE WRIST AND HAND IS AN ADDITIONAL AREA OF CONTROL.

LESSON PLAN #1

UNIT 3--ROBOT CONTROL SYSTEM

ASSIGNMENT SHEET 1

AFTER READING THE INFORMATION SHEET (IS3-1-1, IS3-1-2, IS3-1-3, AND IS3-1-4) PROVIDED, COMPLETE THE FOLLOWING QUESTIONS IN WRITING OR AS REQUESTED BY YOUR INSTRUCTOR.

1. MAKE A DIAGRAM TO EXPLAIN WHAT THE DIFFERENCE BETWEEN AN OPEN-LOOP SYSTEM AND A CLOSED-LOOP SYSTEM IS.

2. WHAT ARE THE ATTRIBUTES OF CLOSED-LOOP SYSTEMS AS COMPARED TO OPEN-LOOP SYSTEMS?

SYLLABUS SHEET FOR LESSON 2
ROBOT SERVICE AND REPAIR

UNIT #3 ROBOT CONTROL SYSTEM

SENSOR AND INTERFACING

LESSON OBJECTIVE--UPON COMPLETION OF THIS LESSON, THE STUDENT SHOULD BE ABLE TO:

TEACHING AIDS:

1. 2-1-H3 SYLLABUS SHEET
2. T3-2-1 WHAT IS A SENSOR?
3. T3-2-2 SENSING STEPS
4. T3-2-3 SENSORS: NON-CONTACT
5. T3-2-4 SENSORS: CONTACT
6. T3-2-5 METHODS OF SENSOR INTERFACE TO THE ROBOT
7. T3-2-6 SENSORS
8. T3-2-7 HOW SENSORS DIFFER

INFORMATIONAL ASSIGNMENTS:

1. IS3-2-1 SENSOR
2. IS3-2-2 SENSOR AND INTERFACING
3. IS3-2-3 HOW SENSORS DIFFER

ANSWER QUESTIONS FOUND ON THE ABOVE ASSIGNMENT SHEETS

1. AS3-2-1 SENSOR AND INTERFACING

REFERENCES:

GROOVER, M.P. AUTOMATION, PRODUCTION SYSTEMS AND COMPUTER AIDED MANUFACTURING. PRENTICE HALL, INC., N.J. 1980.

SAFFORD, E.L. THE COMPLETE HANDBOOK OF ROBOTICS. TAB BOOKS, 1978.

STEP 1--INTRODUCTION FOR PREPARATION OF THE STUDENT:

IN ORDER TO LET THE ROBOTS ACHIEVE A FREEDOM OF MOVEMENT AND TO PERFORM USEFUL FUNCTIONS, THE ROBOT MUST HAVE THE CAPABILITIES TO SENSE AND ACT UPON ITS SURROUNDING ENVIRONMENT.

IN THIS LESSON, THE STUDENT WILL STUDY SOME OF THE METHODS THAT ARE USED TO SENSE THE VARIOUS PARAMETERS A ROBOT MUST MONITOR IN ORDER TO PERFORM A CERTAIN FUNCTION. IN ADDITION, THE STUDENT WILL LEARN HOW A SENSOR INTERFACES WITH ROBOTS.

LESSON SUMMARY AND REVIEW:

1. WHAT IS MEANT BY THE SENSOR?

2. AN ADAPT ROBOT HAS TWO KINDS OF SENSING. WHAT ARE THEY?

3. WHAT IS A RANGE SENSOR?

4. LIST THE METHODS OF SENSOR INTERFACE TO THE ROBOTS.

SENSOR

A SENSOR IS SOME DEVICE WHICH CONVERTS A PHYSICAL PHENOMENON SUCH AS LIGHT, HEAT, SOUND, RADIO WAVES, MAGNETISM OR HUMAN PRESENCE INTO AN ELECTROMECHANICAL SYSTEM INSIDE THE ROBOT, INTO THE INFORMATION REQUIRED FOR GIVEN APPLICATIONS. THE INFORMATION REQUIRED FOR INSPECTION OF PRODUCTS MAY CONSIST OF DIMENSIONS, SHAPES, WEIGHTS, DEFECTS LABELLING, ETC.

THE MAJORITY OF THE ROBOTS USED IN INDUSTRY TODAY HAVE NO ABILITY TO SEE, FEEL OR RESPOND TO THEIR ENVIRONMENT IN ANY WAY. HOWEVER, THE GREAT MAJORITY OF INDUSTRIAL TASKS REQUIRE MORE SOPHISTICATION IN ROBOTS DUE TO THE COMPLEXITIES AND TOO MANY UNCERTAINTIES IN INDUSTRIAL TASKS. SO, IF A ROBOT EQUIPPED A SENSE AND ADAPTED TO ANY CHANGING CIRCUMSTANCES, A CONSIDERABLE INCREASE IN POWER AND FLEXABILITY CAN BE OBTAINABLE.

SENSORY ABILITY IS THE CAPABILITY OF A ROBOT TO SEE, FEEL AND HEAR THROUGH VARIOUS DEVICES (SENSORS). THIS PROVIDES A SOMEWHAT PRIMITIVE BUT USEFUL APPROXIMATION OF HUMAN SENSES TO MACHINES AND PERFORMING CERTAIN HUMAN-LIKE TASKS.

AN ADAPTIVE ROBOT, LIKE HUMANS, MUST DO TWO KINDS OF SENSING:

1. INTERNAL ROBOTIC SENSING, WHICH MONITORS THE STATE OF THE ROBOT'S SYSTEM LIKE INTERNAL TEMPERATURE, AND JOINT LOADS.
2. EXTERNAL ROBOTIC SENSING, WHICH MONITORS THE STATE OF THE ROBOT'S ENVIRONMENT.

SENSING IS PERFORMED IN TWO STEPS: TRANSDUCTING AND PROCESSING. TRANSDUCTING IS A PROCESS OF CONVERTING THE PHYSICAL PROPERTIES INTO AN ELECTRICAL SIGNAL. DEVICES USED FOR THIS PURPOSE ARE CALLED TRANSDUCERS. THE OTHER, PROCESSING, IS TRANSFORMING THE SIGNAL OBTAINED INTO THE REQUIRED INFORMATION, AS SHOWN IN T3-2-2.

SENSORS AND INTERFACING

A GREAT DEAL OF RESEARCH ACTIVITY IS CURRENTLY UNDERWAY TOWARDS DEVELOPMENT OF BOTH GREATER ROBOT CAPABILITY AND MORE SOPHISTICATED COMPUTER CONTROL. THE MAJORITY OF THE RESEARCH SEEMS TO BE AIMED AT MANIPULATOR PATH CONTROL SYSTEMS, DEVELOPMENT OF PROBLEM-ORIENTED LANGUAGES FOR PROGRAMS AND SENSORY FEEDBACK SYSTEMS.

DUE TO THE NEED TO MONITOR THE ENVIRONMENT AND ADAPT THE MANIPULATOR ARM, OPERATIONS BASED ON THE DETECTED CONDITIONS IMPOSES SEVERAL REQUIREMENTS ON THE MANIPULATOR ARM SYSTEMS, SUCH AS, FORCE, TACTILE, AND VISUAL SENSING ARE NECESSARY TO MONITOR THE ENVIRONMENT.

TO TRANSLATE THE DATA FROM SENSORS AND ADAPT THE MANIPULATOR COMMANDS, SOFTWARE IS REQUIRED. THE REQUIRMENTS DEFINE A SYSTEM CONTAINING THE COMPONENTS OF MANIPULATOR ARMS, END EFFECTORS, FORCE AND TACTILE SENSORS, VISION SYSTEMS, COMPUTER HARDWARE AND SOFTWARE SYSTEMS, PROGRAMMABLE PARTS, AND PRESENTATION EQUIPMENT.

AS OF ROBOTIC SENSORS, THERE ARE SEVERAL WAYS TO CLASSIFY THESE SENSORS:

- --NONCONTACT VS. CONTACT SENSING.
- --SENSED PHYSICAL PROPERTIES:
  VISUAL, TEMPERATURE, TOUCH, FORCE, TORQUE, SPECTRAL SIGNATURES.
- --PHYSICAL DIMENSIONALITY OF THE SENSED TARGETS (1 - 3 DIMENSIONS).
- --DIMENSIONALITY OF IMAGE REPRESENTATION:
  A SINGLE POINT, A LINEAR IMAGE, AND A REAL IMAGE.
- --PASSIVE VS. ACTIVE SENSING.
  VISUAL SENSING USING AMBIENT LIGHT VS. CONTROLLED ILLUMINATION.

1. NONCONTACT SENSORS (SEE T3-2-3)
   A. VISUAL SENSORS - USE TV CAMERAS TO SCAN A SCENE AND CONVERT A ROSTER OF REFLECTED LIGHT INTENSITY VALUES INTO ANALOG ELECTRICAL SIGNALS.

   B. RANGE SENSORS - MEASURE THE DISTANCE FROM A REFERENCE POINT TO A ROSTER OF POINTS IN THE SCENE.

2. CONTACT SENSORS (SEE T3-2-4)
   A. TOUCH SENSORS - SENSES AND INDICATES A PHYSICAL CONTACT BETWEEN THE OBJECT CARRYING THE SENSOR AND ANOTHER OBJECT. A SIMPLE TOUCH SENSOR IS A MICRO-SWITCH. BASICALLY THE TOUCH SENSORS ARE USED TO STOP THE MOTION OF A ROBOT WHEN ITS END-EFFECTOR MAKES CONTACT WITH AN OBJECT.
   B. FORCE SENSORS - MEASURES THE THREE COMPONENTS OF FORCE AND THREE COMPONENTS OF TORQUE ACTING BETWEEN TWO OBJECTS. EXISTING FORCE SENSORS EMPLOY DIFFERENCE IN TRANSDUCERS. THE BEST TRANSDUCERS FOR ROBOTS ARE SEMI-CONDUCTOR STRAIN GAUGES CEMENTED ONTO THE COMPLIANT SECTIONS.
3. OTHER ROBOTIC NONCONTACT AND CONTACT SENSORS.
   A. ACOUSTIC SENSORS - SENSES ACOUSTIC WAVES IN GAS (NONCONTACT SENSING), LIQUID, OR SOLID (CONTACT SENSING).
   B. TEMPERATURE SENSORS - BOTH CONTACT AND NONCONTACT.
4. METHODS OF SENSOR INTERFACE TO THE ROBOTS:
   A. DIRECT TO ROBOT.
   B. TO ROBOT VIA PROGRAMMABLE CONTROLLER.
   C. CONVERSION OF ANALOG SIGNALS.
5. RESULTS OF SENSOR INTERFACE TO THE ROBOTS:
   A. ACCORDING TO PROGRAM ROBOT HALTS, BRANCHES, ETC.
   B. ROBOT OR P.C. PROVIDES EXTERNAL OUTPUT.
      EXAMPLE: SHUTS DOWN PRESS. SOUNDS ALARM.

LESSON PLAN #2

UNIT 3--ROBOT CONTROL SYSTEM

ASSIGNMENT SHEET 1

AFTER READING THE INFORMATION SHEETS (IS3-2-1, IS3-2-2, IS3-2-3) PROVIDED, COMPLETE THE FOLLOWING QUESTIONS IN WRITING OR AS REQUESTED BY YOUR INSTRUCTOR.

1. LIST SEVERAL NONCONTACT AND CONTACT SENSORS.

2. WHAT ARE THE BEST FORCE SENSORS USED IN ROBOTS?

3. LIST SIX ITEMS TO DESCRIBE HOW SENSORS DIFFER?

SYLLABUS SHEET FOR LESSON 3
ROBOT SERVICE AND REPAIR

UNIT #3 ROBOT CONTROL SYSTEM

FUNDAMENTALS OF MICROPROCESSOR

LESSON OBJECTIVE--UPON COMPLETION OF THIS LESSON, THE STUDENT SHOULD BE ABLE TO:

TEACHING AIDS:

1. H3-3-1 SYLLABUS SHEET
2. T3-3-1 NUMBER SYSTEM
3. T3-3-2 NUMBER SYSTEM CONVERSION
4. T3-3-3 BINARY COMPLEMENTS
5. T3-3-4 BINARY SIGNED NUMBER
6. T3-3-5 BINARY ARITHMETIC
7. T3-3-6 LOGIC GATES

INFORMATIONAL ASSIGNMENTS:

1. IS3-3-1 MICROPROCESSORS
2. IS3-3-2 LOGIC GATES AND BOOLEAN OPERATION
3. IS3-3-3 MICROPROCESSOR SYSTEM

ANSWER QUESTIONS FOUND ON ASSIGNMENT SHEETS

1. AS3-3-1 FUNDAMENTALS OF MICROPROCESSORS

REFERENCES:

RONY, P.R. INTRODUCTORY EXPERIMENTS IN DIGITAL ELECTRONICS AND 8080A MICROCOMPUTER PROGRAMMING AND INTERFACE. HOWARD W. SAMS AND CO., INC., INDIANAPOLIS, 1982.

LENK, J.D. HANDBOOK OF MICROPROCESSORS, MICROCOMPUTERS AND MINICOMPUTERS. PRENTICE HALL, INC., NEW JERSEY, 1979.

STEP 1-INTRODUCTION FOR PREPARATION OF THE STUDENT:

ALL OF TODAY'S MORE SOPHISTICATED ROBOTS USE SOME SORT OF COMPUTER CONTROL. IT IS VERY IMPORTANT TO UNDERSTAND THIS TYPE OF CONTROL. IN THIS UNIT, YOU WILL BE INTRODUCED TO A BASIC MICROPROCESSOR SYSTEM. IN ADDITION, YOU WILL ALSO LEARN THE NUMBER SYSTEM AND THE SIMPLE LOGIC CIRCUIT. SINCE MICROPROCESSORS USE BINARY NUMBERS FOR DATA AND CONTROL, IT IS IMPORTANT THAT YOU BECOME FAMILIAR WITH THEM.

LESSON SUMMARY AND REVIEW:

1. CONVERT 28_{10} TO A BINARY NUMBER.

2. CONVERT 11010011_2 TO AN OCTAL NUMBER.

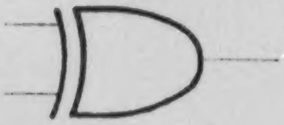
3. CONVERT $8C4_{16}$ TO A BINARY NUMBER.

4. FIND TWO'S COMPLEMENT OF 01001101.

5. THERE ARE THREE BASIC GATES USED IN LOGIC CIRCUITS. THEY ARE __________, __________, AND __________ GATES.

6. WHAT DO THE FOLLOWING SYMBOLS MEAN?

ANSWERS:



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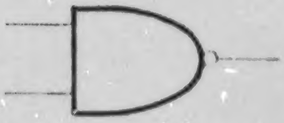

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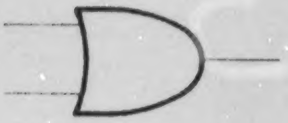

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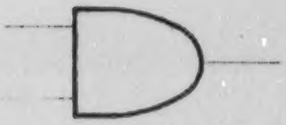

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7. WHAT DO THE RAM, ROM, EPROM MEAN?

MICROPROCESSORS

A MICROPROCESSOR IS AN INTEGRATED CIRCUIT (IC) THAT PERFORMS MANY OF THE FUNCTIONS FOUND IN A DIGITAL COMPUTER. USUALLY A SINGLE MICROPROCESSOR IC IS CAPABLE OF PERFORMING ALL THE ARITHMETIC AND CONTROL FUNCTIONS OF A COMPUTER. BY ITSELF, A TYPICAL MICROPROCESSOR IC DOES NOT CONTAIN THE MEMORIES AND I/O FUNCTIONS OF A COMPUTER. HOWEVER, WHEN THESE FUNCTIONS ARE PROVIDED BY ADDITIONAL ICs, A MICROCOMPUTER IS FORMED.

A MICROPROCESSOR IS NOT ALWAYS USED IN DIGITAL COMPUTER APPLICATIONS. INSTEAD, THE MICROPROCESSOR IS USED AS A CONTROLLER. SOMETIMES, THE MICROPROCESSOR IS CALLED A MICROCONTROLLER WHEN IT IS USED IN THESE CONTROL APPLICATIONS.

1. THE NUMBER OF SYSTEMS IN A MICROPROCESSOR.

   THE DECIMAL NUMBER SYSTEM IS GENERALLY USED IN THE WORLD OUTSIDE THE MICROPROCESSOR. INSIDE A MICROPROCESSOR-BASED SYSTEM, THE BINARY NUMBER SYSTEM IS USED MOST OFTEN. THIS IS BECAUSE BINARY NUMBERS ARE COMPATIBLE WITH THE ELECTRICAL PULSES USED IN DIGITAL OR LOGICAL SYSTEMS. BINARY NUMBERS USE ONLY TWO DIGITS, 0 OR 1. THE ZERO CAN BE PRESENTED BY THE ABSENCE OF A PULSE, WITH THE ONE BEING REPRESENTED BY THE PRESENCE OF A PULSE. THE PULSES CAN BE POSITIVE OR NEGATIVE WITHOUT AFFECTING THE BINARY NUMBER SYSTEM. IN ANY EVENT, TO UNDERSTAND THE LANGUAGE OF MICROPROCESSOR-BASED SYSTEMS (GENERALLY REFERRED TO AS MACHINE LANGUAGE), IT BECOMES NECESSARY TO EXAMINE NUMBER SYSTEMS IN GENERAL AND THE BINARY NUMBER SYSTEM IN PARTICULAR. ALTHOUGH MICROPROCESSORS USE BINARY NUMBERS IN THE FORM OF PULSES, MOST MICROCOMPUTER SYSTEMS USE SOME OTHER FORM OF NUMBER SYSTEM FOR ASSEMBLY OF COMPUTER PROGRAMS. THIS IS BECAUSE BINARY NUMBERS ARE CUMBERSOME WHEN THE VALUES ARE BEYOND A FEW DIGITS. SHORTHAND NUMBER SYSTEMS USED FOR MICROCOMPUTER PROGRAMMING ARE THE OCTAL, HEXIDECIMAL, BINARY-CODED DECIMAL AND ALPHANUMATIC SYSTEMS.

A. DECIMAL SYSTEM

THE DECIMAL SYSTEM IS BASED ON 10 SYMBOLS OR DIGITS: 0, 1, 2, 3, 4, 5, 6, 7, 8, AND 9. ANY NUMBER CAN BE REPRESENTED BY AN ORDERED SET OF THESE, FOR EXAMPLE 4536_{10} (THE SUBSCRIPT INDICATES THE BASE OR RADIX OF THE SYSTEM). THIS NUMBER IS INTERPRETED AS FOLLOWS:

$$\begin{array}{llll} 4 & 5 & 3 & 6_{10}=(4x1000)+(5x100)x(3x10)+(6x1) \\ \downarrow & \downarrow & \downarrow & \downarrow \\ 10^3 & 10^2 & 10^1 & 10^0 \\ 1000 & 100 & 10 & 1 \end{array}$$

NOTICE THAT THE NUMERICAL WEIGHT OF EACH DIGIT INCREASES BY A CONSTANT FACTOR (10) AS THE SET OF DIGITS IS TRAVERSED FROM RIGHT TO LEFT. ALL THE NUMBER SYSTEMS CONSIDERED ARE BASED ON THIS POSITIVE WEIGHTING SYSTEM.

B. BINARY NUMBER SYSTEM

THE BINARY SYSTEM IS BASED ON TWO DIGITS, 0 AND 1. ANY NUMBER CAN BE REPRESENTED BY THESE DIGITS, FOR EXAMPLE, 1011_2; THIS NUMBER MAY BE INTERPRETED AS:

$$\begin{array}{lllll} 1 & 1 & 0 & 1 & 1_2=(1x16)+(1x8)+(0x4)+(1x2)+(1x1)=27_{10} \\ \downarrow & \downarrow & \downarrow & \downarrow & \downarrow \\ 2^4 & 2^3 & 2^2 & 2^1 & 2^0 \\ 16 & 8 & 4 & 2 & 1 \end{array}$$

NOTE THAT THE NUMERICAL WEIGHT OF EACH DIGIT INCREASES BY A CONSTANT FACTOR OF 2 AS THE NUMBER IS TRAVERSED FROM RIGHT TO LEFT. THEREFORE, THE NUMBER 11_{10} IS THE DECIMAL EQUIVALENT OF 1011_2.

YOU SHOULD KEEP IN MIND THAT:

2^4=16 IN DECIMAL NOTATION=16_{10}

2^3=8 IN DECIMAL NOTATION=8_{10}

2^2=4 IN DECIMAL NOTATION=4_{10}

2^1=2 IN DECIMAL NOTATION=2_{10}

2^0=1 IN DECIMAL NOTATION=1_{10}

A BRIEF TABLE THAT ALLOWS YOU TO CONVERT SIMPLE DECIMAL NUMBERS INTO BINARY NUMBERS IS GIVEN AS FOLLOWS.

DECIMAL NUMBER	BINARY NUMBER
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111
16	10000

C. OCTAL NUMBER SYSTEM

THE OCTAL NUMBER SYSTEM IS BASED ON 8 DIGITS: 0, 1, 2, 3, 4, 5, 6, AND 7. ANY NUMBER CAN BE REPRESENTED BY THESE 8 DIGITS. FOR EXAMPLE, 678_8; THIS NUMBER MAY BE INTERPRETED AS FOLLOWS:

$$\begin{array}{lll} 6 & 7 & 3_8=(6x8^2)+(7x8^1)+(3x8^0) \\ \downarrow & \downarrow & \downarrow \\ 8^2 & 8^1 & 8^0=(6x64)+(7x8)+(3x1)=443_{10} \\ 64 & 8 & 1 \end{array}$$

NOTE THAT THE NUMERICAL WEIGHT INCREASES IN A MANNER SIMILAR TO THE PREVIOUS EXAMPLES; FURTHERMORE, THE CONVERSION TO DECIMAL FORM WAS EASILY ACHIEVED AND ILLUSTRATED THAT $448_{10}=678_8$.

THE OCTAL FORM OF THE BINARY NUMBER IS REALIZED AS FOLLOWS:

6	7	3	OCTAL REPRESENTATION
110	111	011	BINARY REPRESENTATION
421	421	421	BINARY WEIGHT

THUS, $673_8 = 443_{10} = 110111011_2$.

D. BINARY CODED DECIMAL (BCD) SYSTEM

THE BCD SYSTEM IS A BINARY SYSTEM BASED ON A 8421 WEIGHTING AND ANY DECIMAL DIGITS CAN BE REPRESENTED BY THESE FOUR DIGITS; FOR EXAMPLE:

8	9	0	DECIMAL PRESENTATION
1000	1001	0000	BCD PRESENTATION
8421	8421	8421	WEIGHTING

THUS, 890_{10} = 100010010000 IS IN BCD NOTATION.

THE DISADVANTAGE WITH THE BCD SYSTEM IS THAT ITS LARGEST DIGIT IS 1001 AND THE FOLLOWING CODES ARE WASTED:

BINARY		DECIMAL
1010	=	10
1011	=	11
1100	=	12
1101	=	13
1110	=	14
1111	=	15

E. HEXADECIMAL NUMBER SYSTEM

THE HEXADECIMAL SYSTEM IS A SYSTEM BASED ON 16 DIGITS AND/OR SYMBOLS: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, AND F. THE SYSTEM UTILIZES ALL THE COMBINATIONS OF THE 8421 WEIGHTED SYSTEM IN THE FOLLOWING WAY. DIGITS 0 9 ASSUME THE BINARY NUMBERS 0000 TO 1001, RESPECTIVELY; THE REMAINING BINARY COMBINATIONS NOW TAKE ON ALPHABETIC CHARACTERS.

HEX	DECIMAL	8421 CODE
A	10	1010
B	11	1011
C	12	1100
D	13	1101
E	14	1110
F	15	1111

A NUMBER REPRESENTED IN HEXADECIMAL NOTATION COULD APPEAR IN THE FOLLOWING FORM: $150D_{16}$. THIS NUMBER MAY BE INTERPRETED AS FOLLOWS:

1 5 0 D_{16}=(1x4096)+(5x256)+(0x16)+(16x1)
↓ ↓ ↓ ↓
16^3 16^2 16^1 16^0=5392_{10}
4096 256 16 1

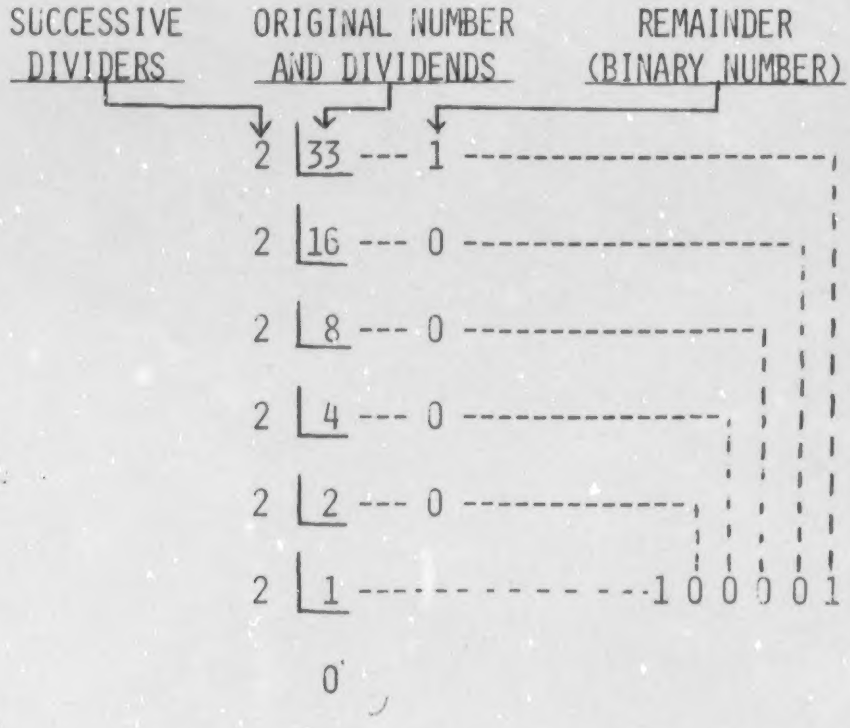
THUS:

$150D_{16} = 5392_{10} = 0001\ 0101\ 0000\ 1110_2$

F. DECIMAL CONVERSION

EXAMPLE 1

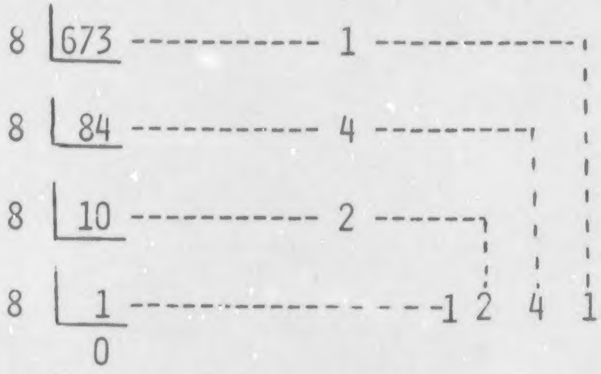
CONVERT 33_{10} TO BINARY FORM.


SUCCESSIVE DIVIDERS
ORIGINAL NUMBER AND DIVIDENDS
REMAINDER (BINARY NUMBER)
2 | 33 --- 1
2 | 16 --- 0
2 | 8 --- 0
2 | 4 --- 0
2 | 2 --- 0
2 | 1 --- 1 0 0 0 0 1
0

$\therefore 33_{10} = 100001_2$

EXAMPLE 2

CONVERT 673_{10} TO OCTAL FORM


8 | 673 --- 1
8 | 84 --- 4
8 | 10 --- 2
8 | 1 --- 1 2 4 1
0

$\therefore 673_{10} = 1241_8$

EXAMPLE 3

CONVERT 543_{10} TO A HEXADECIMAL

```
        16   543 ------- 15(F) ------,
                                     |
        16    33 -------  1 ------,  |
                                  |  |
        16     2 -------  2 -----2 1 F

               0
```

$\therefore 543_{10} = 21F_{16}$

EXAMPLE 4

CONVERT 10011101_2 TO OCTAL, HEXADECIMAL AND DECIMAL NUMBERS

$10011101_2 = 010011\ 101_2 = 235_8$

$10011101_2 = 9C_{16}$

$$10011101_2 = (1x2^7) + (0x2^6) + (0x2^5) + (1x2^4) + (1x2^3) + (1x2^2) + (0x2^1) + (1x2^0)$$
$$= 128 + 16 + 8 + 4 + 1 = 2061_{10}$$

EXAMPLE 5

CONVERT 475_8 TO BINARY, DECIMAL AND HEXADECIMAL NUMBERS

$475_8 = 100111101_2$

$475_8 = (4x8^2)+(7x8^1)+(5x8^0)=317_{10}$

$475_8 = 100111101 = 13C_{16}$

2. BINARY ARITHMETIC

A NUMBER SYSTEM CAN BE USED TO PERFORM TWO BASIC OPERATIONS, ADDITION AND SUBTRACTION; BUT BY USING ADDITION AND SUBTRACTION, YOU CAN THEN PERFORM MULTIPLICATION, DIVISION, AND ANY OTHER NUMERICAL OPERATION.

A. BINARY ADDITION

AS IN THE CASE OF DECIMAL ADDITION, BINARY ADDITION IS ESSENTIALLY A COUNTING PROCESS. THERE ARE FIVE SIMPLE RULES FOR BINARY ADDITION.

0 + 0 = 0 WITH NO CARRY
0 + 1 = 1 WITH NO CARRY
1 + 0 = 1 WITH NO CARRY
1 + 1 = 0 WITH A CARRY OF 1
1 + 1 + 1 = 1 WITH A CARRY OF 1

EXAMPLE 6

BINARY		DECIMAL
1101	(CARRY)	
1101_2	(AUGEND)	13
+ 1101_2	(ADDEND)	+ 13
11010	(SUM)	26

WHEN A MICROPROCESSOR ADDS BINARY NUMBERS, 8-BIT NUMBERS ARE GENERALLY USED.

EXAMPLE 7

1110010	(CARRY)
11110010	(AUGEND)
+ 00111010	(ADDEND)
100101100	(SUM)

* TWO ZEROS WERE ADDED AFTER MSB OF THE ADDEND TO PRODUCE AN 8-BIT NUMBER.

EXAMPLE 8

BINARY		DECIMAL
101.101	(AUGEND)	5.625
+ 1.001	(ADDEND)	+ 1.125
110.110	(SUM)	6.750

B. BINARY SUBTRACTION

THERE ARE ALSO FOUR SIMPLE RULES FOR BINARY SUBTRACTION:

0 - 0 = 0 WITH NO BORROW
1 - 1 = 0 WITH NO BORROW
1 - 0 = 1 WITH NO BORROW
0 - 1 = 1 WITH A BORROW OF 1

EXAMPLE 9

BINARY		DECIMAL
-1-1	(BORROW)	
1001	(MINUEND)	9
- 0111	(SUBTRAHEND)	- 7
0010	(DIFFERENCE)	2

EXAMPLE 10

BINARY		DECIMAL
-1-1-1.-1	(BORROW)	-1.-1
1 0 1. 001	(MINUEND)	5.125
- 1 1. 111	(SUBTRAHEND)	- 3.875
0 0 1. 010	(DIFFERENCE)	1.250

C. BINARY COMPLEMENTS

AS IN THE DECIMAL SYSTEM, BINARY SUBTRACTION CAN BE PERFORMED AS AN ADDITION PROCESS USING THE COMPLEMENT METHOD. THERE ARE TWO TYPES OF BINARY COMPLEMENTS, THE ONE'S COMPLEMENT AND THE TWO'S COMPLEMENT.

1. THE ONE'S COMPLEMENT OF A BINARY NUMBER IS FOUND BY SUBTRACTING EACH DIGIT OF THE NUMBER FROM ONE OR MORE, SIMPLY BY REVERSING THE DIGITS OF THE NUMBER.

EXAMPLE 11

TO FIND THE ONE'S COMPLEMENT OF 10101:

```
  11111
- 10101   (PURE BINARY)
  01010   (ONE'S COMPLEMENT)

              OR

  10101    (PURE BINARY)

  01010    (ONE'S COMPLEMENT)
```

ALTHOUGH THE ONE'S COMPLEMENT SYSTEM HAS CERTAIN PROBLEMS AND IS NOT GENERALLY USED FOR MICROPROCESSOR-BASED SYSTEMS, THE ONE'S COMPLEMENT NUMBER MUST BE FOUND AS THE FIRST STEP IN FINDING A TWO'S COMPLEMENT NUMBER.

2. TWO'S COMPLEMENT - THE TWO'S COMPLEMENT SYSTEM IS IN GENERAL USE FOR MICROCOMPUTER ARITHMETIC SYSTEMS.

EXAMPLE 12
CONVERT 00001011 INTO TWO'S COMPLEMENT FORM

1. FORM A IS A COMPLEMENT OF THE ORIGINAL NUMBER. CHANGE THE 1'S TO 0'S AND 0'S TO 1'S AS FOLLOWS:

$$00001011 \longrightarrow 11110100$$

2. ADD 1 AT THE LEAST SIGNIFICANT POSITION OF THE 1'S COMPLEMENT FORM.

$$11110100 + 1 \longrightarrow 11110101$$

3. TWO'S COMPLEMENT ARITHMETIC
   A CHARACTERISTIC OF THE TWO'S COMPLEMENT SYSTEM IS THAT BOTH SIGNED AND UNSIGNED NUMBERS CAN BE ADDED BY THE SAME CIRCUIT.

EXAMPLE 13
ADD THE UNSIGNED NUMBER 132_{10} AND 14_{10}

$$\begin{array}{rcr} 10000100 & \text{(ADDEND)} & 132_{10} \\ +\ 00001110 & \text{(AUGEND)} & +\ 14_{10} \\ \hline 10010010 & & 146_{10} \end{array}$$

EXAMPLE 14
IF THE INPUT ARE TWO'S COMPLEMENT SIGNED NUMBERS, THEN THE EXAMPLE ABOVE--THE ADDEND, AUGEND, AND SUM ARE:

$$\begin{array}{rr} 10000100_2 & -124_{10} \\ +\ 00001110_2 & +\ 14_{10} \\ \hline 10010010_2 & 110_{10} \end{array}$$

4. TWO'S COMPLEMENT SUBTRACTION

IN MOST MICROCOMPUTER SYSTEMS, BINARY NUMBERS ARE SUBTRACTED BY ADDING THE TWO'S COMPLEMENT OF THE SUBTRAHEND TO THE MINUDE AND IGNORING THE CARRY BIT.

EXAMPLE 15

$$\begin{array}{rcrcl} \underline{\text{ON PAPER}} & & & & \underline{\text{IN MICROCOMPUTER}} \\ 00001010_2 & & 10_{10} & & 00001010 \\ \underline{-\ 00000011_2} & \Rightarrow & 3_{10} & \Rightarrow + & \underline{11111101} \text{ (TWO'S COMPLEMENT)} \\ 00000111_2 & & 7_{10} & & 100000111 \end{array}$$

↑ IGNORE CARRY BIT.

D. BINARY ARITHMETIC WITH SIGNED NUMBERS

1. ADDING POSITIVE NUMBERS

EXAMPLE 16

$$\begin{array}{rr} \underline{0}0000111_2 & +7 \\ \underline{+\ \underline{0}0000011_2} & \underline{+3} \\ \underline{0}0001010_2 & +10 \end{array}$$

THE SIGN BITS ARE UNDERLINE . IN SIGNED NUMBERS, THE MSB IS THE SIGN BIT. USUALLY, AN 0 REPRESENTS "+", AND A 1 REPRESENTS A "_".

2. ADDING POSITIVE AND NEGATIVE NUMBERS

EXAMPLE 17

$$\begin{array}{rr} 00000111_2 & +7 \\ \underline{+\ 11111101_2} & \underline{+(-3)} \\ 100000100_2 & +4 \end{array}$$

↑ DISCARD FINAL CARRY.

3. ADDING NEGATIVE NUMBER

EXAMPLE 18

BINARY	DECIMAL
11111101_2	(-3)
+ 11111100_2	+ (-4)
111111001	-7

↑ DISCARD FINAL CARRY.

E. BINARY MULTIPLICATION

THERE ARE FOUR RULES FOR BINARY MULTIPLICATION.

--0x0 = 0
--0x1 = 0
--1x0 = 0
--1x1 = 1

EXAMPLE 19

BINARY		DECIMAL
10101	(MULTIPLICAND)	21
x 10	(MULTIPLIER)	x 2
00000	(FIRST PARTIAL PRODUCT)	42
10101	(SECOND PARTIAL PRODUCT)	
101010	(FINAL PRODUCT)	

EXAMPLE 20

BINARY		DECIMAL
10.01	(MULTIPLICAND)	2.25
x 1.01	(MULTIPLIER)	x 1.25
10 01	(PARTIAL	11.25
00 00	PRODUCTS)	45 0
10 01		225
10.1101	(FINAL PRODUCTS)	6.8125

F. BINARY DIVISION

BINARY DIVISION IS PERFORMED IN MUCH THE SAME WAY AS DECIMAL LONG DIVISION. THERE ARE TWO RULES IN USE:

-- 0 ÷ 1 = 0
-- 1 ÷ 1 = 1

EXAMPLE 21

```
     ________
1011)10000100
     1011
      1011
      1011
      0000
```

LOGIC GATES AND BOOLEAN OPERATION

1. GATE

A GATE IS A CIRCUIT THAT HAS TWO OR MORE INPUTS AND ONE OUTPUT.

THERE ARE FOUR COMMON GATES USED IN LOGIC CIRCUITS: THE AND OR NAND, AND NOR GATES. A SOMEWHAT MORE COMPLICATED GATE THAT CAN BE CONSTRUCTED FROM NAND OR NOR GATES IS THE EXCLUSIVE OR GATE. BEFORE WE DESCRIBE THESE GATES, WE MUST DESCRIBE THE CONCEPT OF A TRUTH TABLE FIRST.

2. TRUTH TABLE

A TRUTH TABLE IS A TABULATION THAT SHOWS THE RELATIONSHIP OF ALL OUTPUT LOGIC 0, AND LOGIC 1 STATES OF A DIGITAL CIRCUIT TO ALL POSSIBLE COMBINATIONS OF INPUT LOGIC 0 AND LOGIC 1, STATES IN SUCH A WAY AS TO CHARACTERIZE THE CIRCUIT FUNCTIONS COMPLETELY.

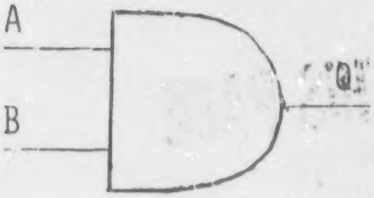
TRUTH TABLES ARE USED BECAUSE THEY ARE SIMPLE AND CONVENIENT SHORT-HAND REPRESENTATIONS OF DIGITAL CIRCUITS. IT IS MUCH EASIER TO WRITE A TRUTH TABLE THAN TO EXPLAIN IN WORDS HOW A SPECIFIC DIGITAL CIRCUIT OPERATES. THE MORE INPUTS AND OUTPUTS THAT EXIST, THE MORE OBVIOUS THE ADVANTAGE OF A TRUTH TABLE OVER ANY WRITTEN OR VERBAL DESCRIPTION. WE USE TRUTH TABLES TO REPRESENT DIGITAL CIRCUITS JUST AS ELECTRICAL ENGINEERS USE CIRCUIT DIAGRAMS TO PRESENT ELECTRONIC DEVICES.

3. AND GATES AND THEIR OPERATIONS

THE AND GATE FUNCTION PRODUCES THE LOGICAL PRODUCT OF TWO OR MORE LOGIC VARIABLES. IT FUNCTIONS AS A SERIES OF CIRCUITS IN AN ELECTRICAL SYSTEM.

THE BEHAVIOR OF A 2 INPUT AND GATE IS DESCRIBED AS FOLLOWS: IF INPUT A IS LOGIC 1 AND INPUT B IS LOGIC 1, THEN OUTPUT Q IS LOGIC 1, OTHERWISE, OUTPUT Q IS LOGIC 0, AS SHOWN IN FIGURE 3-3-1.

FIG. 3-3-1
TWO INPUT AND GATE AND ITS TRUTH TABLE



INPUTS		OUTPUT
A	B	Q
0	0	0
0	1	0
1	0	0
1	1	1

AND OPERATIONS REFER TO THE EXAMPLE AS SHOWN BELOW.

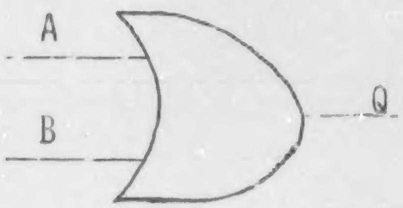
EXAMPLE 22
A ONE 8-BIT BINARY NUMBER IS ANDED WITH A SECOND 8-BIT BINARY NUMBER

	8-BIT NUMBER	·	8-BIT NUMBER	=	RESULTS	
MSB	1	·	1	=	1	MSB
	0	·	1	=	0	
	0	·	1	=	0	
	1	·	0	=	0	
	1	·	0	=	0	
	1	·	0	=	0	
	0	·	1	=	0	
LSB	1	·	1	=	1	LSB

4. OR GATE AND ITS OPERATION

THE SYMBOL AND TRUTH TABLE FOR A 2-INPUT OR GATE ARE GIVEN AS SHOWN IN FIGURE 3-3-2.

FIG. 3-3-2
OR GATE SYMBOL AND ITS TRUTH TABLE



INPUT		OUTPUT
A	B	Q
0	0	0
0	11	1
1	0	1
1	1	1

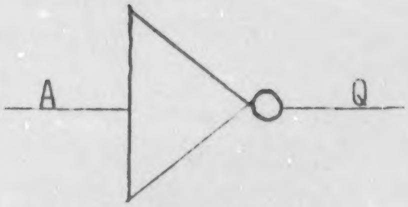
EXAMPLE 23

ONE 8-BIT BINARY NUMBER IS ORed WITH A SECOND 8-BIT BINARY NUMBER

	8-BIT NUMBER		8-BIT NUMBER		RESULT	
MSB	1	+	1	=	1	MSB
	0	+	0	=	0	
	0	+	1	=	1	
	1	+	1	=	1	
	1	+	0	=	1	
	0	+	0	=	0	
	1	+	0	=	1	
LSB	1	+	1	=	1	LSB

5. NOT GATE AND ITS OPERATION

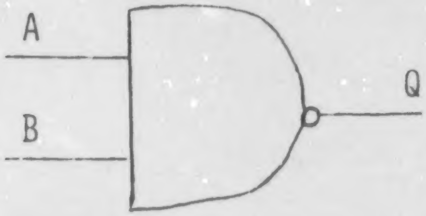
THE SYMBOL AND TRUTH TABLE FOR AN INVERTER ARE SHOWN IN FIGURE 3-3-3:



INPUT	OUTPUT
A	Q
0	1
1	0

6. NAND GATE AND ITS OPERATION

THE SYMBOL AND TRUTH TABLE FOR A NAND GATE ARE SHOWN IN FIGURE 3-3-4:



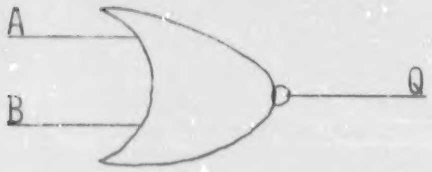
INPUT		OUTPUT
A	B	Q
0	0	1
0	1	1
1	0	1
1	1	0

EXAMPLE 24
A ONE 8-BIT BINARY NUMBER IS NAND'ED WITH A SECOND 8-BIT [illegible]

	8-BIT NUMBER	·	8-BIT NUMBER	=	RESULTS	
MSB	1	·	1	=	1	MSB
	0	·	1	=	0	
	0	·	1	=	0	
	1	·	0	=	0	
	1	·	0	=	0	
	1	·	0	=	0	
	0	·	1	=	0	
LSB	1	·	1	=	1	LSB

7. NOR GATE AND ITS OPERATION

THE SYMBOL AND ITS TRUTH TABLE FOR A NOR GATE ARE SHOWN IN FIGURE 3-3-5:



INPUT		OUTPUT
A	B	Q
0	0	1
0	1	0
1	0	0
1	1	0

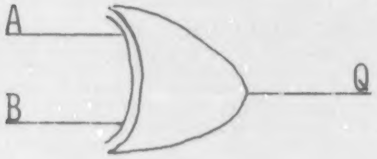
BEST COPY AVAILABLE

EXAMPLE 25

	8-BIT NUMBER	.	8-BIT NUMBER	=	RESULTS	
MSB	1	+	0	=	0	MSB
	0	+	0	=	1	
	1	+	1	=	0	
	1	+	0	=	0	
	0	+	0	=	1	
	0	+	0	=	1	
	1	+	1	=	0	
LSB	0	+	1	=	0	LSB

8. EXCLUSIVE--OR GATE AND ITS OPERATION

THE SYMBOL AND ITS TRUTH TABLE FOR AN EXCLUSIVE OR ARE SHOWN IN FIGURE 3-3-6:



INPUT		OUTPUT
A	B	Q
0	0	0
0	1	1
1	0	1
1	1	0

EXAMPLE 26

$1 \oplus 1 = 0$ MSB

$0 \oplus 1 = 1$

$0 \oplus 0 = 0$

$1 \oplus 0 = 1$

$1 \oplus 0 = 1$

$1 \oplus 1 = 0$

$0 \oplus 1 = 1$

$0 \oplus 0 = 0$ LSB

BASIC MICROPROCESSOR SYSTEM

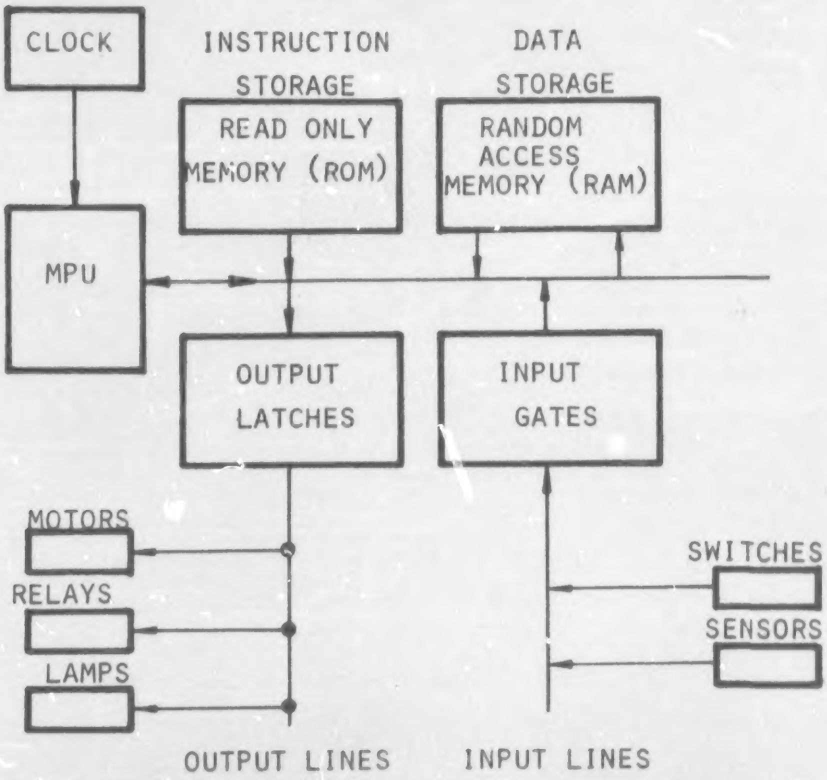
1. TERMS
   - * BITS - THE ELEMENTARY UNIT OF INFORMATION IS CALLED THE BIT, WHICH IS AN ABBREVIATION FOR BINARY DIGIT.
   - * NIBBLES - A NIBBLE IS GENERALLY CONSIDERED TO BE FOUR BITS.
   - * BYTES - A BYTE IS A GROUP OF EIGHT BITS THAT OCCUPY A SINGLE MEMORY LOCATION IN MOST OF MICROCOMPUTERS.
   - * WORDS - A WORD, IN GENERAL, IS THE NUMBER OF BITS THAT A MACHINE CAN MANIPULATE SIMULTANEOUSLY. IF THE NUMBER OF BITS IN A WORD IS EIGHT, WE USUALLY USE THE TERM BYTE RATHER THAN THE TERM WORD.
2. MICROPROCESSOR SYSTEM

ALL DIGITAL COMPUTERS FROM THE VERY LARGE MACHINES DOWN TO THE SMALLEST MICROPROCESSOR SYSTEM CONTAIN THREE BASIC SECTIONS:

A. CENTRAL PROCESSING UNIT (CPU) OR MICROPROCESSOR UNIT (MPU).
B. MEMORY: EPROM, ROM, RAM AND SO ON.
C. AN INPUT/OUTPUT SECTION FOR COMMUNICATION WITH ITS PERIPHERALS.

A TYPICAL PROCESSOR SYSTEM IS SHOWN IN FIGURE 3-3-7, WHICH ILLUSTRATES ITS BASIC FORM.

FIG. 3-3-7
MICROPROCESSOR SYSTEM


CLOCK
INSTRUCTION STORAGE
DATA STORAGE
READ ONLY MEMORY (ROM)
RANDOM ACCESS MEMORY (RAM)
MPU
OUTPUT LATCHES
INPUT GATES
MOTORS
RELAYS
LAMPS
SWITCHES
SENSORS
OUTPUT LINES
INPUT LINES

3. MICROPROCESSOR UNIT (MPU)

THE MPC CONSISTS OF A NUMBER OF BASIC ELEMENTS: AN ARITHMETIC LOGIC UNIT (ALU), SEVERAL ACCUMULATORS (STORAGE REGISTERS FOR WORK IN PROCESS), GENERAL PURPOSE REGISTERS (TEMPORARY STORAGE DEVICES), PROGRAM COUNTER (A REGISTER THAT STORES THE ADDRESS OF THE NEXT INSTRUCTION), INSTRUCTION REGISTER (THE INSTRUCTION BEING EXECUTED), A CONDITION CODES REGISTER AND A CONTROL UNIT.

A. ARITHMETIC LOGIC UNIT (ALU) - THE ALU USES LOGIC MANIPULATION, SUCH AS AND, OR, EXCLUSIVE OR, AND COMPLEMENTS AND SHIFTS TO PERFORM THE ARITHMETIC FUNCTIONS REQUIRED. THE CONDITION CODE FLAGS, WHICH ARE GENERATED WITHIN THE ALU, ASSUME A PREDETERMINED STATE ACCORDING TO THE OUTCOME OF THE LAST INSTRUCTION PERFORMED.

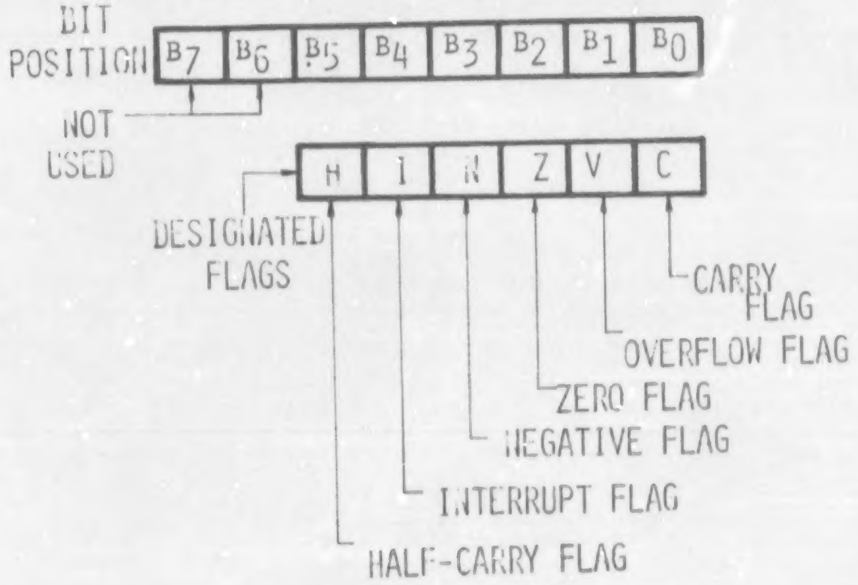
B. ACCUMULATORS (ACC) - THE ACCUMULATORS ARE USED TO PASS DATA INTO AND OUT OF THE MPU, AS WELL AS TO HOLD DATA FOR FURTHER MANIPULATION.

C. PROGRAM COUNTER (PC) - THE PROGRAM COUNTER KEEPS TRACK OF THE LOCATION OF THE NEXT INSTRUCTION TO BE EXCUTED FROM PROGRAM MEMORY. AFTER EACH FETCH FROM MEMORY THE PROGRAM COUNTER IS AUTOMATICALLY INCREMENTED BY 1. THE ADDRESS OF THE START OF THE PROGRAM TO BE EXECUTED IS PLACED IN THE PC, WHICH IS THEN INCREMENTED ONE STEP AT A TIME AS THE PROCESSOR EXECUTES THE PROGRAM.

D. INSTRUCTION REGISTER (IR) - THE INSTRUCTION REGISTER RECEIVES EACH CURRENT INSTRUCTION FROM MEMORY AND HOLDS IT UNTIL IT HAS BEEN EXECUTED; THEN THE NEXT INSTRUCTION IS LOADED IN, WHICH SIMULTANEOUSLY DESTROYS THAT WHICH IS ALREADY IN THE REGISTER.

E. CONDITION CODES REGISTER (CC) - THE CONDITION CODES REGISTER CONTAINS THE FLAGS THAT ARE USED TO INDICATE THE OUTCOME OF THE PREVIOUS OPERATION. THE CONTENTS OF THIS REGISTER AREUSED AS PART OF THE DECISION-MAKING PROCESS OF THE PROCESSOR. THE FORMAT OF THE REGISTER IS SHOWN IN FIG. 3-3-8.

FIG. 3-3-8
REGISTER FORMAT


BIT POSITION
B7
B6
B5
B4
B3
B2
B1
B0
NOT USED
H
I
N
Z
V
C
DESIGNATED FLAGS
CARRY FLAG
OVERFLOW FLAG
ZERO FLAG
NEGATIVE FLAG
INTERRUPT FLAG
HALF-CARRY FLAG

1. BIT 0 IS THE CARRY FLAG AND, WHEN SET, IS USED TO INDICATE THE FOLLOWING:
    - A. THAT A CARRY OUT OF THE B_7 POSITION OF THE DESIGNATED ACCUMULATOR OR MEMORY LOCATION HAS OCCURRED.
    - B. THAT A BORROW HAS OCCURRED AS A RESULT OF THE PRECEDING SUBTRACTION OPERATION.
    - C. THAT A PARTICULAR BIT IN AN ACCUMULATOR OR MEMORY LOCATION IS SET.
2. BIT 1 IS THE V BIT. IT PRESENTS THE STATUS OF THE OVERFLOW FLAG.
3. BIT 2 IS THE Z FLAG. IT IS SET ANYTIME THE RESULT OF THE LAST DATA MANIPULATION, ARITHMETIC OR LOGIC OPERATION, CAUSED THE RESULT TO BE ZERO. THIS FLAG FINDS ITS MAJOR USE IN THE EXACT DETERMINATION OF THE MAGNITUDE OF A NUMBER.
4. BIT 3 IS THE N FLAG. IT IS SET IF BIT 7 OF THE SPECIFIED ACCUMULATOR OR MEMORY LOCATION IS 1. THIS MEANS THAT THE RESIDENT NUMBER IS NEGATIVE, IN SIGNED NUMBERS ARITHMETIC.

5. BIT 4 REPRESENTS THE STATUS OF THE INTERRUPT MASK BIT.
6. BIT 5 IS THE HALF CARRY BIT. IT IS SET WHEN A CARRY OCCURS FROM THE LOWER 4 BIT TO THE UPPER 4 BITS IN AN ACCUMULATOR OR MEMORY LOCATION.

F. CONTROL UNIT - THE CONTROL UNIT DIRECTS THE OPERATION OF THE MPU AND IS ACTUALLY A COMPUTER INSIDE A COMPUTER. THAT IS, IT HAS ALL THE FUNCTIONAL ELEMENTS OF A CLASSICAL COMPUTER, INCLUDING READ-ONLY MEMORY (ROM).

4. MEMORY UNIT

MEMORY IS USED TO STORE THE USER'S PROGRAM AND/OR INFORMATION OR DATA AND IS OF TWO BASIC TYPES:

A. VOLATILE - STORED INFORMATION IS LOST WHEN THE POWER TO THE MEMORY IS SWITCHED OFF.

B. NONVOLATILE - STORED INFORMATION IS RETAINED WHEN POWER IS REMOVED, I.E., PERMANENT MEMORY.

MOST MICROPROCESSOR SYSTEMS USE A COMBINATION OF RAM AND ROM. RAM ALLOWS THE PROCESSOR TO STORE AND RETRIEVE DATA FROM THAT PORTION OF THE MEMORY. HOWEVER, THE DATA IN ROM ARE PROGRAMMED IN DURING MANUFACTURE BY THE SEMICONDUCTOR MANUFACTURER; ACCORDING TO SPECIFICATIONS SET UP BY THE USER, THE PROGRAM CAN NOT BE ALTERED. EPROM (ERASABLE PROGRAMMABLE ROM) CAN HAVE THE COMPLETE CONTENTS ERASED BY SUBJECTING THE EPROM TO ULTRA VIOLET LIGHT. HOWEVER, TO WRITE IN THE NEW CONTENTS REQUIRES SPECIAL EQUIPMENT.

5. I/O UNIT

THE INPUT/OUTPUT SECTION IS USED TO CONNECT THE PROCESSOR TO THE EXTERNAL DATA SOURCES AND DATA DESTINATIONS. ALL OF WHICH FORM PART OF THE PERIPHERAL DEVICES CONNECTED TO THE SYSTEM.

A. INPUT DEVICES

-KEYBOARDS AND CONSOLES
-PUNCHED CARD READERS
-PUNCHED TAPE READERS
-OPTICAL OR MAGNETIC CHARACTER READERS
-LIGHT PEN

B. OUTPUT DEVICES

-TYPEWRITERS
-LINE PRINTERS
-CARD PUNCHES
-TAPE PUNCHES
-CATHODE RAY TUBE CONSOLES
-PLOTTERS

LESSON PLAN #3

UNIT 3--ROBOT CONTROL SYSTEM

ASSIGNMENT SHEET 1

AFTER READING THE INFORMATION SHEET (IS3-3-1, IS3-3-2, IS3-3-3) PROVIDED, COMPLETE THE FOLLOWING QUESTIONS IN WRITING OR AS REQUESTED BY YOUR INSTRUCTOR.

1. COMPLETE THE FOLLOWING TABLE.

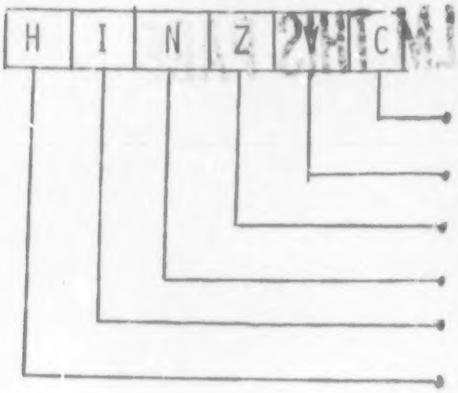
BINARY	DECIMAL	OCTAL	HEXADECIMAL
10110110			
	63		
		33	
			BE

2. CALCULATE THE FOLLOWING MULTIPLICATION.

$$\begin{array}{r} 10.01_2 \\ \times\ 1.01_2 \\ \hline \end{array}$$

3. THERE ARE THREE BASIC SECTIONS IN ALL DIGITAL COMPUTERS. WHAT ARE THEY?

4. WHAT IS MEANT BY THE FOLLOWING CONDITION CODES?



5. WHAT IS THE DIFFERENCE BETWEEN VOLATILE AND NONVOLATILE MEMORY?

SYLLABUS SHEET FOR LESSON 1
ROBOT SERVICE AND REPAIR

UNIT #4 SERVICE AND REPAIR

ELECTRONIC METERS AND THEIR TECHNIQUES

LESSON OBJECTIVE--UPON COMPLETION OF THIS LESSON THE STUDENT SHOULD BE ABLE TO:

1. VERBALLY DEFINE THE TERMS ASSOCIATED WITH VOLTAGE AND MEASURE THE VOLTAGE DROPS IN A DC CIRCUIT.
2. VERBALLY DEFINE THE TERMS ASSOCIATED WITH CURRENT AND MEASURE THE CURRENT WITH AN AMMETER AND CONVERT AMPERES TO MILLIAMPS AND MICOAMPS.
3. VERBALLY DEFINE THE TERMS ASSOCIATED WITH RESISTANCE AND SHOW THE ABILITY TO MEASURE CIRCUIT RESISTANCE WITH AN OHMMETER.

TOOLS AND MATERIALS:

1. MULTIMETER
2. VOLTMETER
3. THREE DIFFERENT BATTERIES
4. LAMP
5. SWITCH
6. DC AMMETER
7. DC POWER SOURCE

TEACHING AIDS:

1.	H4-1-1	SYLLABUS SHEET
2.	T4-1-1	VOLTAGE
3.	T4-1-2	VOLTAGE SYMBOLS AND DEFINITIONS
4.	T4-1-3	DC VOLTMETER APPLICATION
5.	T4-1-4	VOLTMETER SCALE AND RANGE SWITCH
6.	T4-1-5	KIRCHHOFF'S LAW OF VOLTAGE
7.	T4-1-6	CURRENT
8.	T4-1-7	CURRENT SYMBOLS
9.	T4-1-8	PREFIXES
10.	T4-1-9	SERIES AND PARALLEL CIRCUIT
11.	T4-1-10	AMMETER APPLICATION
12.	T4-1-11	TYPICAL AMMETER
13.	T4-1-12	RESISTANCE
14.	T4-1-13	SYMBOL USED FOR RESISTANCE AND RESISTORS
15.	T4-1-14	OHMMETER

INFORMATIONAL ASSIGNMENT:

1.	IS4-1-1	VOLTAGE AND ITS MEASURING TECHNIQUE
2.	IS4-1-2	CURRENT AND ITS MEASURING TECHNIQUE
3.	IS4-1-3	VOLTAGE
		ANSWER QUESTIONS FOUND ON ASSIGNMENT SHEETS
1.	AS4-1-1	EXPERIMENT

REFERENCES:

1. MILES, RITTER-SANDERS, ELECTRONIC METERS: TECHNIQUES AND TROUBLESHOOTING, RESTON PUBLISHING COMPANY, INC., VIRGINIA, 1977.

STEP 1 - INTRODUCTION FOR PREPARATION OF THE STUDENT:

IN THE FIELD OF ELECTRICITY AND ELECTRONICS, AS IN ALL OF THE OTHER PHYSICAL SCIENCES, ACCURATE QUANTITATIVE MEASUREMENTS ARE ESSENTIAL. THESE INVOLVE TWO IMPORTANT ITEMS - NUMBERS AND UNITS.

A TECHNICIAN COMMONLY WORKS WITH AMMETERS, VOLTMETERS, OHMMETERS IN MAINTAINING AND TROUBLESHOOTING ELECTRICAL AND ELECTRONIC EQUIPMENT. TO THE TECHNICIAN; A GOOD UNDERSTANDING OF THE FUNCTIONAL DESIGN AND OPERATION OF ELECTRICAL INSTRUMENTS IS IMPORTANT.

IN ELECTRICAL OR ELECTRONIC SERVICING PROCEDURES, ONE OR MORE OF THE FOLLOWING METHODS ARE COMMONLY USED TO DETERMINE IF THE CIRCUITS IN A UNIT OF EQUIPMENT ARE FUNCTIONING NORMALLY.

A. USE A VOLTMETER TO DETERMINE THE VOLTAGE EXISTING BETWEEN TWO POINTS IN A CIRCUIT.
B. USE AN AMMETER TO MEASURE THE AMOUNT OF CURRENT FLOWING IN A CIRCUIT.
C. USE AN OHMMETER TO CHECK FOR CIRCUIT CONTINUITY AND TO MEASURE TOTAL AND PARTIAL CIRCUIT RESISTANCE.

IF THIS LESSON PLAN, THE STUDENT WILL UNDERSTAND AND KNOW HOW TO USE ELECTRONIC METERS TO DO MAINTENANCE AND TROUBLESHOOTING WORKS.

LESSON SUMMARY AND REVIEW:

INTERACTIVE ITEMS:

1. DEFINITION:
   A. VOLTAGE:

   B. CURRENT FLOW:

   C. AMPERE:

   D. RESISTANCE:

2. SYMBOL AND ABBREVIATION.
   KV=
   MV=
   PA=
   A =
   V =

4. CONVERT THE FOLLOWING ITEMS:
   A. 2 AMPS=__________MILLIAMPS
   B 0.0550A=__________MA
   C. 4 AMPS=__________MA
   D. 2.45 MA=__________A
   E. .35=_____________MA
   F. 2,360,000MA=_____A

VOLTAGE AND ITS MEASURING TECHNIQUES

I. TERMINOLOGY

TERMS	DESCRIPTION
VOLTAGE	ELECTRICAL FORCE OR PRESSURE THAT CAUSES THE FLOW OF ELECTRICAL CURRENT.
VOLTAGE DROP	DIFFERENCE IN VOLTAGE MEASURED ACROSS A COMPONENT IN A CIRCUIT.
VOLT	THE UNIT OF MEASUREMENT OF ELECTROMOTIVE FORCE.
VOLTMETER	INSTRUMENT USED TO MEASURE VOLTAGE.
VOLTAGE SOURCE	COMMON VOLTAGE SOURCES ARE BATTERIES, GENERATORS/ALTERNATORS, ELECTRONIC POWER SUPPLIES.

II. VOLTAGE SYMBOLS AND DEFINITIONS

SYMBOLS	DEFINITIONS
EMF	ELECTROMOTIVE FORCE
E	VOLTAGE SOURCE OR APPLIED VOLTAGE
V	VOLTAGE OR VOLTAGE DROP KV--KILOVOLT (10^3 V) MV--MEGAVOLT (10^6 V) mV--MILLIVOLT (10^{-3} V) uV--MICROVOLT (10^{-6} V)
VM	VOLTMETER

III. BASIC PARTS OF A VOLTMETER

MULTIMETER AND ELECTRONIC METER HAVE SEVERAL SCALES FOR INDICATION OF ELECTRICAL QUANTITIES SUCH AS DC VOLTAGE, AC VOLTAGE, RESISTANCE, DC CURRENT, AND DECIBEL VALUES. A SCALE PLATE FOR A TYPICAL MULTIMETER IS SHOWN IN FIG. 4-1-1. CONTROLS FOR SELECTION OF VARIOUS FUNCTIONS AND RANGES ARE PROVIDED, THESE ARE SHOWN IN FIG. 4-1-2. IN THIS EXAMPLE, THREE CONTROLS ARE AVAILABLE, ONE CONTROL SWITCHES THE INSTRUMENT CIRCUITRY FOR INDICATION OF +DC, -DC, OR AC VOLTAGE VALUES. THE OTHER CONTROL SELECTS FIVE VOLTAGE RANGES, FIVE CURRENT RANGES AND THREE RESISTANCE RANGES. A ZERO OHMS CONTROL IS ALSO PROVIDED TO SET THE POINTER PRECISELY AT THE END OF THE OHMS SCALE WHEN THE INSTRUMENT IS OPERATED ON A RESISTANCE RANGE. IN ADDITION, THE CONNECTING LEADS OR PROBES ARE ALSO NEEDED.

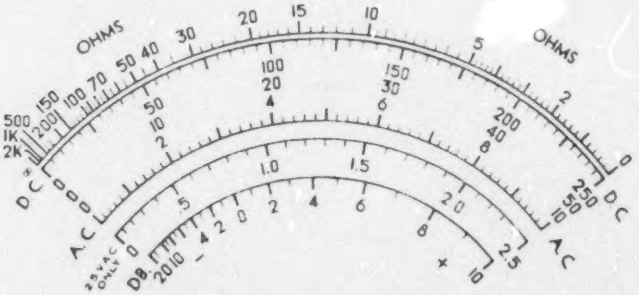

OHMS
30
20
15
10
5
OHMS
2
0
500
1K
2K
150
200
100
70
50
40
50
10
2
100
20
4
150
30
6
200
40
8
250
50
10
D.C
D.C
A.C
A.C
1.0
1.5
2.0
2.5
0
5
2.5 VAC ONLY
DB.
20
10
4
2
0
2
4
6
8
10
-
+

FIG. 4-1-1 A SCALE PLATE FOR A MULTIMETER

IV. PROCEDURES FOR USING A VOLTMETER

A. HOLD PROBES BY INSULATED PART.

B. ASSURE THAT METER WILL READ EXPECTED VOLTAGE.

C. SET RANGE SWITCH FOR CORRECT RANGE.

D. USE CORRECT POLARITY OF PROBES.

   1. NEGATIVE PROBE TOWARD NEGATIVE OF POWER SUPPLY.
   2. POSITIVE PROBE TOWARD POSITIVE OF POWER SUPPLY.

E. CONNECT VOLTMETER IN PARALLEL WITH LOAD. SHOWN IN FIG. 4-1-4.

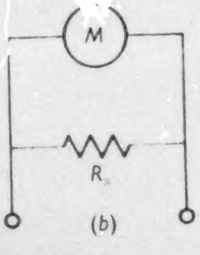


FIG. 4-1-4
CONNECT DIAGRAM

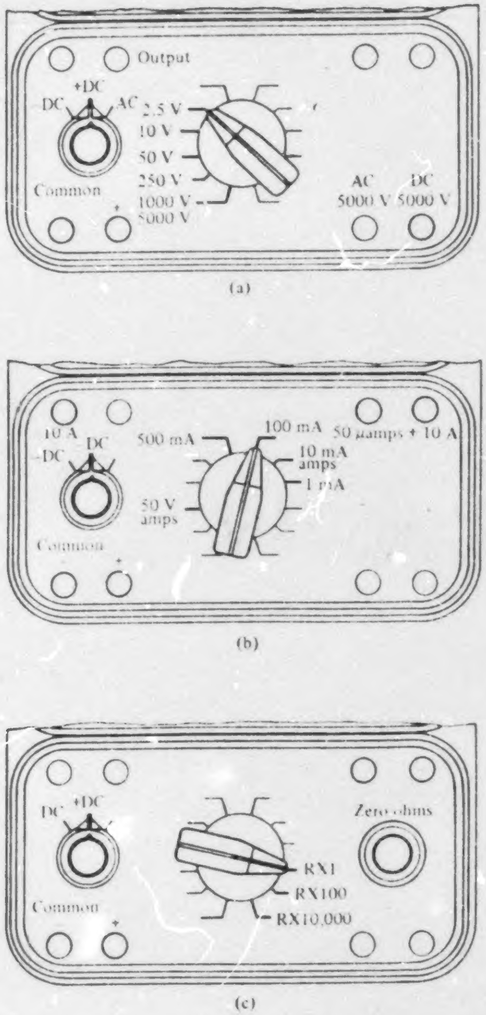

Output
+DC
-DC
AC
2.5 V
10 V
50 V
250 V
1000 V
5000 V
Common
+
AC 5000 V
DC 5000 V
(a)
10 A
-DC
DC
500 mA
100 mA
50 μamps + 10 A
10 mA amps
1 mA
50 V amps
Common
+
(b)
DC
+DC
Zero ohms
RX1
RX100
RX10,000
Common
+
(c)

FIG. 4-1-2
DC VOLTAGE (A) CURRENT (B), AND RESISTANCE (C) RANGES ASSOCIATED WITH THE SCALE PLATE SHOWN IN FIG. 4-1-1.

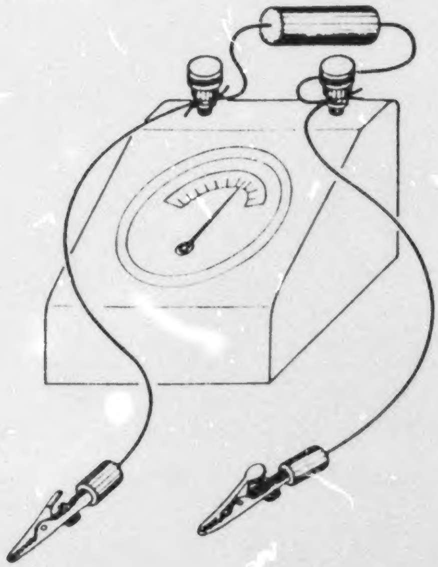


FIG. 4-1-3
CONNECTING PROBES

F. READ VOLTAGE ON METER

G. REMOVE PROBES

V. KIRCHOFF'S LAW OF VOLTAGE

THE ALGEBRAIC SUM OF THE VOLTAGE DROPS AROUND A CLOSED LOOP MUST EQUAL THE APPLIED VOLTAGE, THIS IS SHOWN IN FIG. 4-1-5.

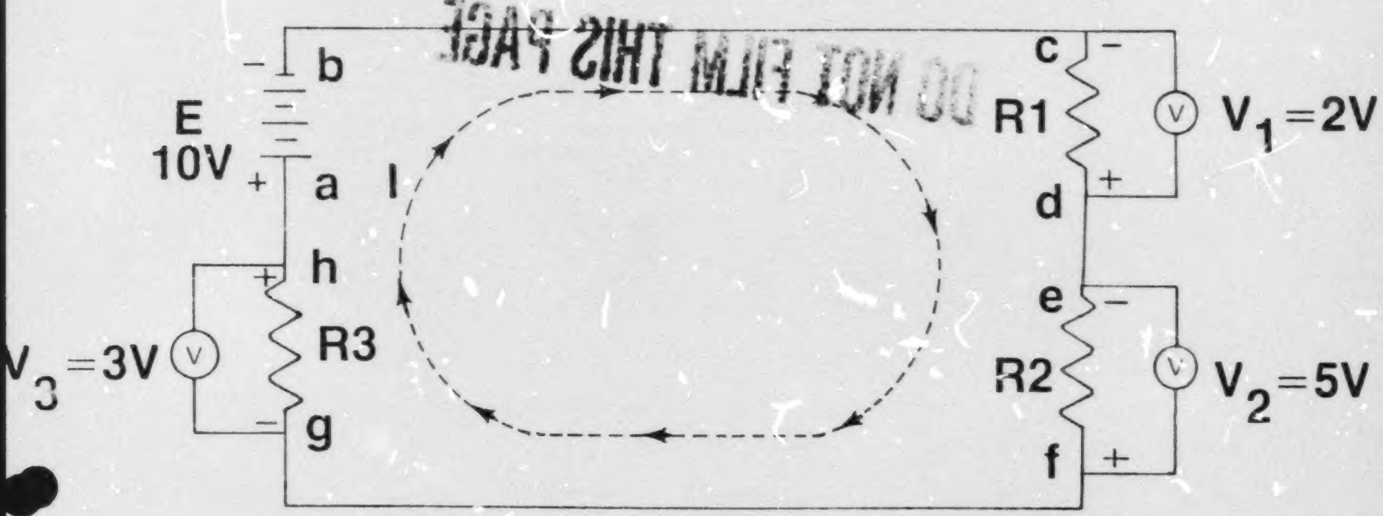


FIG. 4-1-5. VOLTAGE DROPS IN A RESISTIVE CIRCUIT
(DIRECTION OF ELECTRON FLOW: NEGATIVE (B)--POSITIVE(A))

APPLIED VOLTAGE (E) = 10V

$V_1 = 2V$

$V_2 = 5V$

$V_3 = 3V$

APPLICATION OF KIRCHOFF'S LAW OF VOLTAGE

$V_1 + V_2 + V_3 = E$

$2 + 5 + 3 = 10$

CURRENT AND ITS MEASURING TECHNIQUES

I. TERMIMOLOGIES

TERMS	DESCRIPTION
CURRENT	THE FLOW OF ELECTRONS THROUGH A CIRCUIT
DIRECT CURRENT	CURRENT THAT FLOWS THROUGH A CIRCUIT IN ONE DIRECTION ONLY, FROM THE NEGATIVE SIDE OF THE POWER SOURCE THROUGH THE CIRCUIT TO THE POSITIVE SIDE OF THE POWER SOURCE.
ALTERNATING CURRENT	CURRENT THAT CHANGES DIRECTION OF FLOW AT A CERTAIN RATE. FOR EXAMPLE: 60 HERTZ-PER-SECOND HOUSE CURRENT CHANGES DIRECTION OF FLOW 120 TIMES EACH SECOND.
SERIES CIRCUIT	A CIRCUIT IN WHICH THE PARTS OR COMPONENTS ARE CONNECTED END-TO-END SO THAT THE SAME CURRENT FLOWS THROUGHOUT THE ENTIRE CIRCUIT.
PARALLEL CIRCUIT	A CIRCUIT WITH MULTIPLE PATHS FOR CURRENT FLOW.
COULOMB	A QUANTITY OF 6.28×10^{18} ELECTRONS.
AMPERE	THE UNITE OF MEASUREMENT OF ELECTRICAL CURRENT.
AMMETER	INSTRUMENT USED FOR MEASURING ELECTRICAL CURRENT.

II. CURRENT SYMBOLS

SYMBOLS	EXPLANATION
I	CURRENT
A OR AMP	AMPERE
Q OR Q	COULOMB
Ⓐ OR Ⓐ	AMMETER
MA	MILLIAMP (10^{-3} AMP)
uA	MICROAMP (10^{-6} AMP)
PA	PICOAMP (10^{-12} AMP)

III. PROCEDURES FOR MEASURING CURRENT WITH A DC AMMETER.

A. SET RANGE SWITH TO EXPECTED CURRENT VALUES.

B. OPEN THE CIRCUIT BY DISCONNECTING A CONDUCTOR CONNECTION OR BY OPENING A SWITCH.

C. OBSERVING PROPER POLARITY (NEGATIVE PROBE TOWARD NEGATIVE SIDE OF POWER SOURCE, POSITIVE PROBE TOWARD POSITIVE SIDE OF POWER SOURCE), CONNECT AMMETER IN SERIES WITH THE CIRCUIT.

D. READ CURRENT INDICATION PROPER SCALE, DEPENDING ON RANGE SWITH SETTING.

E. DISCONNECT AMMETER FROM CIRCUIT AND RECONNECT OR CLOSE CIRCUIT.

NOTE: MEASURING INSTRUMENTS INDICATE MORE ACCURATELY TOWARD THE CENTER OF THE SCALE. SELECT A RANGE WHICH WILL ALLOW READING THE EXPECTED CURRENT IN THE MIDDLE HALF OF SCALE.

NEVER CONNECT AN AMMETER IN PARALLEL TO A LOAD.

RESISTANCE

I. TERMINOLOGIES

TERMS	EXPLANATION
RESISTANCE	OPPOSITION WHICH A DEVICE OR MATERIAL OFFERS TO THE FLOW OF ELECTRIC CURRENT.
RESISTOR	A CIRCUIT COMPONENT SPECIFICALLY DESIGNED TO OPPOSE THE FLOW OF ELECTRICAL CURRENT.
OHM	THE UNIT OF MEASUREMENT OF RESISTANCE ONE OHM = A RESISTANCE PRESENT WHEN A POTENTIAL DIFFERENCE OF ONE BOLT CAUSE A CURRENT OF ONE AMPERE.
OHMMETER	AN INSTRUMENT USED FOR MEASURE.
WATTAGE RATING	THE MAXIMUM AMOUNT OF ELECTRICAL POWER (VOLTAGE OR CURRENT) THAT CAN BE APPLIED TO A RESISTOR.
TOLERANCE	THE PERCENTAGE ABOVE OR BELOW THAT A RESISTOR'S VALUE CAN DIFFER FROM ITS SPECIFIED VALUE.
FIXED RESISTOR	A RESISTOR WITH A RESISTANCE VALUE THAT CANNOT BE VARIED.
ADJUSTABLE RESISTOR	A RESISTOR WITH A RESISTANCE VALUE THAT CAN BE CHANGED. COMMON METHODS OF ADJUSTMENT INCLUDE A MOVEABLE TAB, SCREW DRIVER ADJUSTMENT, CONTROL KNOB, OR SIMILAR DEVICE.

II. PREFERRED RESISTANCE VALUES

AS SHOWN IN FIG. 4-1-6, THIS IS A CHART OF PREFERRED RESISTANCE VALUES FOR RESISTOR WITH TOLERANCE OF ±20%, ±10%, AND ±5%. THIS CHART IS BASED ON USA STANDARD C83.2. THE PREFERRED VALUES MEANS THAT THE U.S. GOVERNMENT RECOMMENDS THAT MANUFACTURES MAKE AND SUPPLY RESISTORS IN THESE VALUES TO STORES.

THE REASONS FOR PREFERRED VALUES ARE:

A. HELPS LIMIT THE NUMBER OF PARTS THAT ARE NEEDED TO BE MANUFACTURED AND STOCKED.

B. HELPS INSURE AVAILABILITY OF INTERCHANGEABLE RESISTORS.

20%	10%	5%
10	10	10
--	--	11
--	12	12
--	--	13
15	15	15
--	--	16
--	18	18
22	22	22
--	--	24
--	27	27
--	--	30
33	33	33
--	--	36
--	39	39
--	--	43
47	47	47
--	--	51
--	56	56
--	--	62
68	68	68
--	--	75
--	82	82
--	--	91
100	100	100

FIG. 4-1-6 PREFERRED RESISTANCE VALUES

TO FIND RESISTANCE VALUES LARGER OR SMALLER THAN THE NUMBERS GIVEN IN THE TABLE, MULTIPLY THE GIVEN NUMBER BY THE PROPER MULTIPLE OF TEN. (.01, .1, 10, 100, 1,000, ETC.) FOR EXAMPLE, THE 30 IN THE CHART UNDER THE ±5% COLUMN MEANS THAT RESISTORS WITH ±5% TOLERANCE CAN BE PURCHASED IN DECIMAL MULTIPLE SUCH AS .3, 3, 30, 300, 3,000, OR 30,000. DASHES IN THE ±10% AND ±20% COLUMNS INDICATE RESISTANCE VALUES THAT ARE NOT AVAILABLE IN THESE TOLERANCES.

III. SYMBOLS USED FOR RESISTANCE AND RESISTORS.

ITEM	SYMBOL
OHM	Ω
KILOHM	K OR KΩ
MEGOHM	M OR M
RESISTOR	R
FIRST, SECOND, THIRD ETC. RESISTOR	R_1, R_2, R_3 ETC.

IV. PARTS OF AN OHMMETER

A. INDICATOR

B. SCALE

C. RANGE SELECTOR SWITCH

R x 1 = MULTIPLY INDICATION BY 1.

R x 1000 = MULTIPLY INDICATION BY 1,000.

R x 10,000 = MULTIPLY INDICATION BY 10,000.

D. CONNECTING LEADS

E. OHM ADJUST OR ZERO ADJUST CONTROL

V. RESISTANCE MEASURING PROCEDURE

A. CONNECT THE EQUIPMENT IN ACCORDANCE WITH FIG. 4-1-7, USING ONE DRY CELL.

B. DISCONNECT Rx AND ADJUST R FOR FULL SCALE DEFLECTION OF THE METER.

C. CONNECT AND ADJUST Rx FOR HALF-SCALE DEFLECTION.

D. RECORD THIS VALUE OF Rx ON PROPER SCALE.

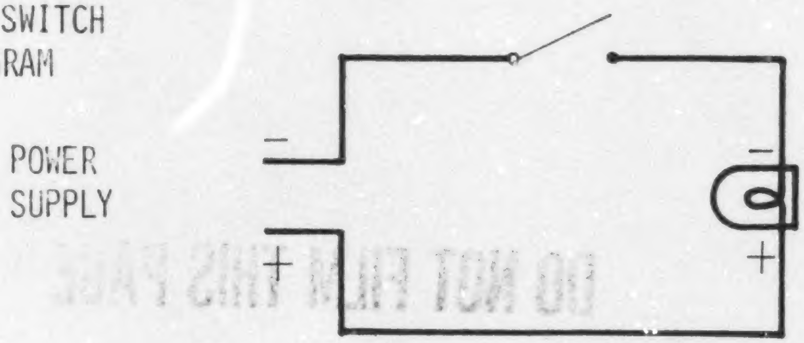
E. DISCONNECT OHMMETER FROM THE MEASUREMENT.

EXPERIMENT I

1. MEASURE AND COMPOSE THE VOLTAGE OF THREE DIFFERENT BATTERIES.
2. TOOLS AND EQUIPMENT
   - A. MULTIMETER OR VOLTMETER WITH LEADS
   - B. THREE BATTERIES WITH DIFFERENT VOLTAGE.
3. PROCEDURE
   - A. CHECK TO SEE THAT THE METER IS A DC METER, OR IF IT IS A MULTIMETER, MAKE SURE IT IS SET TO DC.
   - B. PLACE THE TEST LEADS IN THEIR PROPER CONNECTORS IN THE METER.
   - C. SET THE FULL SCALE READING ON THE VOLTMETER HIGHER THAN THE EXPECTED VOLTAGE.
   - D. HOLD THE TEST LEADS BY THE INSULATED PART.
   - E. CONNECT THE NEGATIVE LEAD TO THE NEGATIVE TERMINAL OF A BATTERY, THEN CONNECT THE POSITIVE LEAD TO THE POSITIVE TERMINAL OF THE BATTERY.
   - F. READ AND RECORD THE VOLTMETER INDICATION.
   - G. DISCONNECT ONE OF THE METER LEADS AND AFTER THE VOLTMETER GOES TO ZERO, RECONNECT THE LEAD.
   - H. READ AND RECORD THE VOLTMETER INDICATION AGAIN.
   - I. REPEAT STEPS F, G, AND H A THIRD TIME.
   - J. REPEAT STEP F, G, AND H, FOR EACH OF THE OTHER TWO BATTERIES UNTIL YOU RECORD A TOTAL OF NINE VOLTMETER READINGS.
   - K. RETURN METERS AND BATTERIES TO PROPER STORAGE AREA.

EXPERIMENT 2

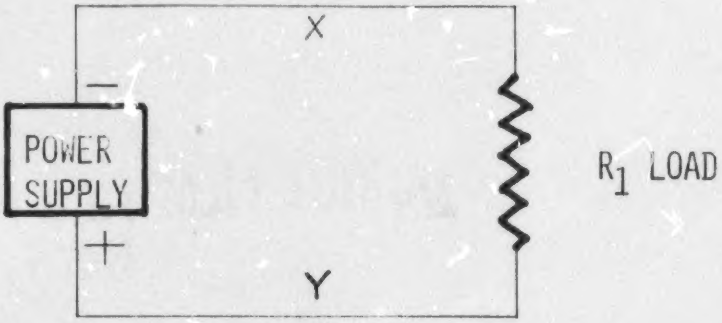
1. MEASURE THE VOLTAGE DROP IN A DC CIRCUIT.
2. TOOLS AND EQUIPMENT
   - A. VOLTMETER
   - B. POWER SUPPLY
   - C. LAMP OR LOAD
   - D. SWITCH
3. DIAGRAM



4. PROCEDURE
   - A. CONNECT THE POWER SUPPLY TO THE LAMP OR LEAD AS SHOWN IN THE DIAGRAM ABOVE.
   - B. CLOSE THE SWITCH.
   - C. CONNECT THE VOLTMETER ACROSS THE POWER SUPPLY AND ADJUST FOR 1½ VOLTS.
   - D. READ AND RECORD THE VOLTMETER INDICATION.
   - E. CONNECT THE VOLTMETER ACROSS THE LAMP OR LOAD.
   - F. READ AND RECORD THE VOLTMETER INDICATION.
   - G. CONNECT THE VOLTMETER TO THE POSITIVE TERMINAL OF THE POWER SUPPLY AND TO THE POSITIVE TERMINAL OF THE LAMP.
   - H. READ AND RECORD THE VOLTMETER INDICATION.
   - I. WITH THE SWITCH STILL CLOSED, MEASURE AND RECORD THE VOLTAGE ACROSS THE SWITCH.
   - J. WITH THE VOLTMETER STILL CONNECTED TO THE SWITCH, OPEN THE SWITCH.
   - K. READ AND RECORD THE VOLTMETER INDICATION WITH THE SWITCH OPEN.
   - L. RETURN METER AND MATERIALS TO PROPER STORAGE AREA.

EXPERIMENT 3

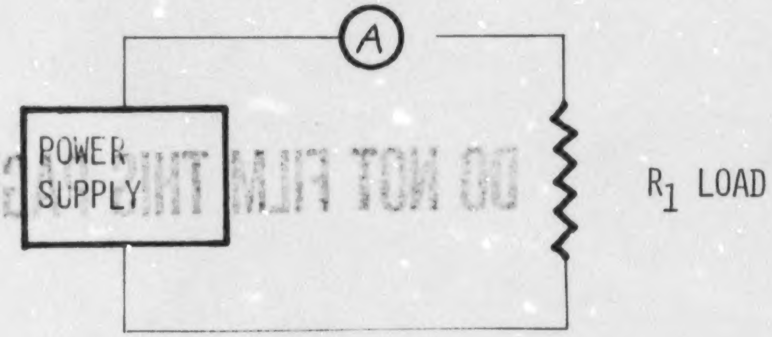
1. MEASURE AND COMPARE CURRENTS AT TWO POINTS OF A CIRCUIT.
2. TOOLS AND EQUIPMENT
   - A. DC AMMETER
   - B. DC POWER SOURCE
   - C. LOAD (LAMP OR OTHER RESISTANCE)
3. DIAGRAM



4. PROCEDURE
   - A. WIRE THE SCHEMATIC AS SHOWN IN DIAGRAM ABOVE, SET POWER SOURCE AT 1½ VDC..
   - B. MEASURE AND RECORD CURRENT AT POINT X ON THE DIAGRAM ABOVE.
   - C. MEASURE AND RECORD CURRENT AT POINT Y ON THE DIAGRAM ABOVE.
   - D. COMPARE CURRENT MEASUREMENTS.
   - E. RETURN METER AND MATERIALS TO PROPER STORAGE AREA.

EXPERIMENT 4

1. MEASURE AND COMPARE CURRENTS IN A CIRCUIT AT TWO DIFFERENT VOLTAGE LEVELS.
2. TOOLS AND EQUIPMENT
   - A. DC AMMETER
   - B. DC POWER SOURCE
   - C. LOAD (LAMP OR OTHER RESISTANCE)
3. DIAGRAM



4. PROCEDURE
   - A. CONNECT THE CIRCUIT AS SHOWN IN THE DIAGRAM ABOVE, SET THE DC POWER SOURCE AT 1½ VDC.
   - B. MEASURE AND RECORD THE CURRENT IN THE CIRCUIT AMPERAGE.
   - C. INCREASE POWER SOURCE TO 3 VDC.
   - D. MEASURE AND RECORD THE CURRENT.
   - E. COMPARE CURRENT MEASUREMENTS.
   - F. RETURN METER AND MATERIALS TO PROPER STORAGE AREA.

EXPERIMENT 5

1. MEASURE CIRCUIT RESISTANCE WITH AN OHMMETER.
2. TOOLS AND MATERIALS
    A. OHMMETER OR MULTIMETER WITH OHMMETER CAPABILITY.
    B. FIVE ASSORTED RESISTORS WITH COLOR CODE MAKINGS.
    C. ONE AMP OR LIKE BULK.
3. PROCEDURE
    A. READ AND RECORD THE VALUE OF EACH RESISTOR AS INDICATED BY THE COLOR CODE MAKINGS.
    B. CONNECT THE OHMMETER TO EACH RESISTOR AND RECORD THE MEASURED VALUE BESIDE THE COLOR CODED VALUE.
    C. WRITE "IN" IF THE MEASURED VALUE IS WITHIN THE TOLERANCE INDICATED BY THE COLOR CODE MAKINGS AND WRITE "OUT" IF THIS IS NOT TRUE.
    D. MEASURE AND RECORD THE RESISTANCE OF THE LAMP.
    E. RETURN TOOLS AND MATERIALS TO PROPER STORAGE AREA.

LESSON PLAN #1

UNIT 4--ELECTRONIC METERS AND THEIR TECHNIQUES

ASSIGNMENT SHEET 1

AFTER READING THE INFORMATION SHEETS (IS4-1-1 THROUGH IS4-1-3) PROVIDED, COMPLETE THE FOLLOWING QUESTIONS IN WRITING OR AS REQUESTED BY YOUR INSTRUCTOR.

1. ____________________ IS THE DIFFERENCE IN VOLTAGE MEASURED ACROSS A COMPONENT IN A CIRCUIT.
2. INSTRUMENT USED TO MEASURE VOLTAGE IS CALLED A ____________.
3. MV = ____________________.
4. MULTIMETER AND ELECTRONIC METERS HAVE SEVERAL SCALES FOR INDICATION OF ELECTRICAL QUANTITIES SUCH AS ____________, ____________, ____________, ____________, AND DECIBEL VALUES.
5. A CIRCUIT WITH MULTIPLE PATHS FOR CURRENT FLOW IS CALLED ____________________.
6. ____________ IS THE UNIT OF MEASUREMENT OF ELECTRICAL CURRENTS.
7. pA = ______________________________.
8. ________________ IS AN OPPOSITION WHICH A DEVICE OR MATERIAL OFFERS TO THE FLOW OF ELECTRIC CURRENTS.
9. ________________ IS A RESISTOR WITH A RESISTANCE VALUE THAT CANNOT BE VARIED.
10. RANGE SELECTOR SWITCH:
    R x 1 = ____________________________
    R x 1000 = ____________________________
11. KIRCHHOFF'S LAW OF VOLTAGE IS:
    ____
    ____
    ____
    ____

H4-2-1

SYLLABUS SHEET FOR LESSON 2
ROBOT SERVICE AND REPAIR

UNIT #4 SERVICE AND REPAIR

MAINTENANCE AND SERVICE

LESSON OBJECTIVE--UPON COMPLETION OF THIS LESSON, THE STUDENT SHOULD BE ABLE TO:

1. VERBALLY DESCRIBE THE ROBOT MAINTENANCE CONDITIONS AND EXPLAIN HOW TO DO IT.
2. VERBALLY DESCRIBE THE GENERAL TROUBLESHOOTING PRINCIPLES AND THEIR PROCEDURES IN DIFFERENT SITUATIONS.

TOOLS AND MATERIALS:

1. STANDARD HAND TOOLS
2. MICROMETER
3. DEPTH GAUGE
4. OHMMETER
5. VOLTMETER
6. ALIGNMENT TOOL

TEACHING AIDS:

H4-2-1	SYLLABUS SHEET
T4-2-1	ROBOT ARM
T4-2-2	ROBOT ARM (JOINT)
T4-2-3	CONTROL SYSTEM, BLOCK DIAGRAM

INFORMATIONAL ASSIGNMENT:

IS4-2-1	MAINTENANCE
IS4-2-2	TROUBLESHOOTING AND SERVICE
	ANSWER QUESTIONS FOUND ON ASSIGNMENT SHEET
AS4-2-1	MAINTENANCE AND SERVICE

REFERENCES:

1. ENGLEBERGER, JOSEPH F., ROBOTICS IN PRACTICE: MANAGEMENT AND APPLICATIONS OF INDUSTRIAL ROBOTS, AMERICAN MANAGEMENT ASSOCIATICN, NEW YORK, 1980.

STEP 1--INTRODUCTION FOR PREPARATION OF THE STUDENT:

IT IS SAID MAINTENANCE IS MORE IMPORTANT THAN REPAIR. THERE ARE TWO SECTIONS THAT WILL BE COVERED IN THIS PLAN: MAINTENANCE AND TROUBLESHOOTING AND SERVICE. IN THIS LESSON PLAN, THE STUDENT WILL LEARN AND UNDERSTAND HOW TO MAINTAIN AN INDUSTRIAL ROBOT, AND IF THE ROBOT DOES SOMETHING WRONG, THEY WILL BE ABLE TO FIND OUT AND REPAIR IT.

LESSON SUMMARY AND REVIEW:

1. WHICH TWO PARTS OF A ROBOT ARE REGULARLY REQUIRED FOR MAINTENANCE?

2. THE BEARINGS IN THE PUMA ROBOT ARM ARE DESIGNED FOR ______________.

3. IN BACKLASH ADJUSTMENT, WITH WHICH PARTS ARE WE USUALLY DEALING?

4. WHAT KINDS OF TOOLS AND EQUIPMENT ARE USED FOR TROUBLESHOOTING AND SERVICE?

5. BEFORE WE DO TROUBLESHOOTING, WHAT DO WE NEED TO ENSURE FIRST?

6. WHEN ______________ or ______________ POWER TURNED ON, DO NOT REPLACE COMPONENTS OR MAKE ADJUSTMENT TO A ROBOT.

I. MAINTENANCE

A. GENERAL CONSIDERATIONS

TO OBTAIN OPTIMUM PERFORMANCE. MAINTENANCE OF A ROBOT MUST BE PERFORMED REGULARLY BY USERS. REGULAR MAINTENANCE IS REQUIRED ON THE ROBOT ARM AND CONTROLLER, CONSISTING OF THE FOLLOWING:

	ITEM	DESCRIPTION
1.	ROBOT ARM	LUBRICATE GEARS EVERY 1000 HOURS OF OPERATING TIME. CHECK GEAR TRAINS FOR BACKLASH EVERY 1000 HOURS OF OPERATING TIME. CHECK BEARING FOE WEAR OR INADEQUATE PRELOAD EVERY 2000 HOURS OF OPERATING TIME. CHECK SHOULDER FOR ELECTRICAL HARNESS WEAR EVERY 2000 HOURS OF OPERATING TIME.
2.	CONTROLLER	CLEAN OR REPLACE AIR FILTERS IN ACCORDANCE WITH ENVIRONMENTAL CONDITIONS. CLEAN WITH CLEAR WATER OR APPROPRIATE CLEANING SOLVENT.

THE ROBOT ARM IS THE MECHANICAL COMPONENT OF THE SYSTEM INCORPORATING 6 DEGREES OF FREEDOM (5 DEGREES OF PUMA 550), EACH CONTROLLED BY A DC SERVOMOTOR. IT IS SUFFICIENTLY FLEXIBLE TO BE TAUGHT A WIDE VARIETY OF TASKS. EACH MEMBER OF THE ROBOT ARM IS CONNECTED TO ANOTHER MEMBER AT A JOINT, MUCH LIKE A HUMAN ARM AND TORSO. THROUGH EACH JOINT PASSES ONE OR MORE AXES AROUND WHICH THE MEMBERS OF THE ARM ROTATE. THE MEMBERS OF THE ROBOT ARM ARE SHOWN IN FIGURE 4-2-1. THEY ARE THE TRUNK, SHOULDER, UPPER ARM, FOREARM, WRIST, AND GRIPPER. THE ROBOT ARM MEMBERS CONTAIN THE VARIOUS SERVOMOTORS AND GEAR TRAINS.

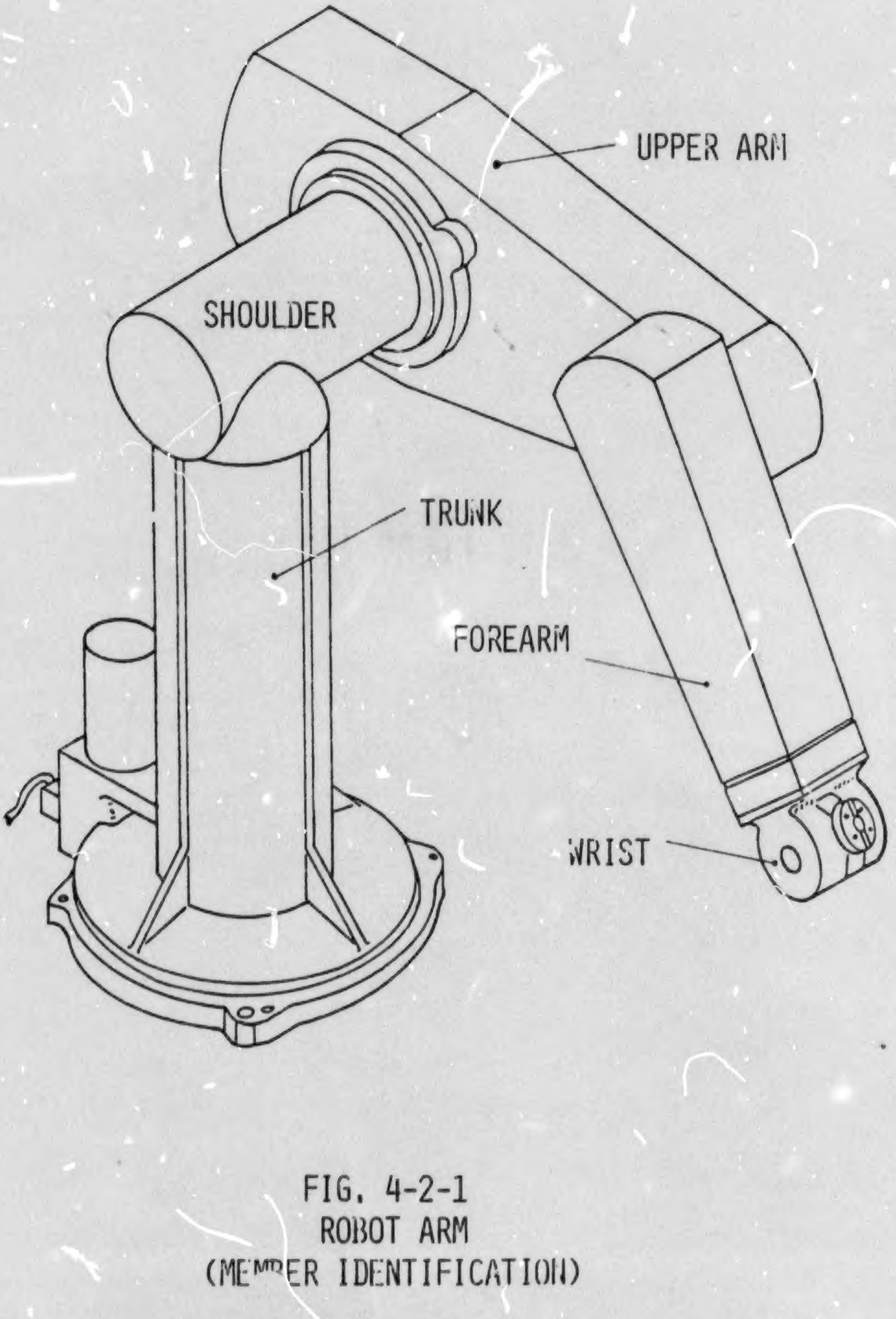

UPPER ARM
SHOULDER
TRUNK
FOREARM
WRIST

FIG. 4-2-1
ROBOT ARM
(MEMBER IDENTIFICATION)

THE AXES OF ROTATION AND THE RANGES OF ROTATION ARE SHOWN IN FIG. 4-2-2.

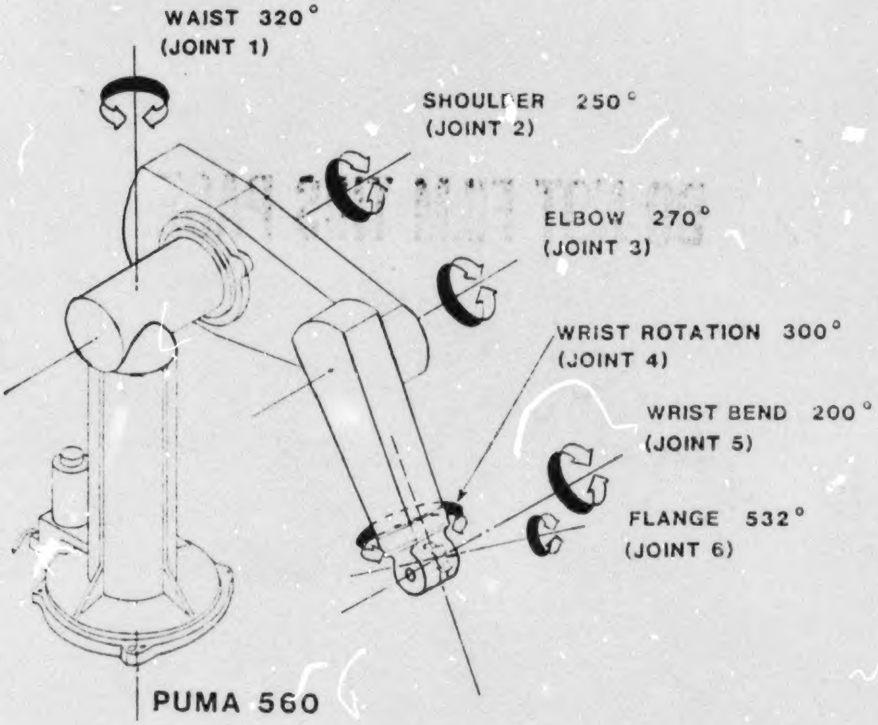

WAIST 320°
(JOINT 1)
SHOULDER 250°
(JOINT 2)
ELBOW 270°
(JOINT 3)
WRIST ROTATION 300°
(JOINT 4)
WRIST BEND 200°
(JOINT 5)
FLANGE 532°
(JOINT 6)
PUMA 560

FIG. 4-2-2
ROBOT ARM
(DEGREE OF JOINT ROTATION)

B. GEAR LUBRICATION

ITEM	DESCRIPTION
1. WAIST JOINT	REMOVE PLASTIC PLUG IN BASE OF ROBOT ARM. PRESS FREE BUTTON ON TEACH PENDANT. THEN PRESS JOINT 1 MOTION PUSH BUTTON ON THE PLUS SIDE. USING A FLEXIBLE APPLICATION. APPLY GREASE TO EDGE OF GEAR TEETH. MOVE JOINT 1 AS REQUIRED SO THAT GREASE CAN BE APPLIED TO FOUR OR FIVE SPOTS AROUND THE CIRCUMFERENCE OF THE GEAR.
2. SHOULDER JOINT	REMOVE SIDE PANEL. LOCATE THE GEAR REDUCTION HOUSING AT SHOULDER END OF UPPER ARM. APPLY GREASE THROUGH GREASE FITTING. REPLACE THE SIDE PANEL.
3. ELBOW	REMOVE PANEL. LOCATE GEAR REDUCTION HOUSING AT ELBOW END OF UPPER ARM. APPLY GREASE THROUGH THE TWO GREASE FITTINGS. REPLACE SIDE PANEL.

C. BEARING WEAR OR INADEQUATE PRELOAD

THE FOLLOWING PROCEDURES FOR DETERMINING IF BEARING WEAR OR INADEQUATE PRELOAD EXISTS IN EACH JOINT AND WHAT CORRECTIONS CAN BE MADE.

ITEMS	DESCRIPTIONS
1. GENERAL	THE BEARINGS IN THE ROBOT ARM ARE DESIGNED FOR LONG LIFE. THEY SHOULD BE CHECKED EVERY 2000 HOURS OF OPERATING TIME OR SOONER IF BACKLASH IN A GEAR TRAIN IS SUSPECTED. TO CHECK FOR BEARING WEAR OR INADEQUATE PRELOAD, PRESS ARM POWER OFF PUSH BUTTON ON CONTROLLER FRONT PANEL. MOTOR BRAKES ARE ROW SET.
2. WAIST JOINT	BEARING IN WAIST JOINT IS FACTOR SET AND CANNOT BE SERVICED BY THE USER. CHECK THE BEARINGS BY TRYING TO ROCK THE SHOULDER BACK AND FORTH ACROSS THE WAIST AXIS. IF ANY LOOSENESS IS PRESENT, REPLACE BEARING AS DESCRIBED IN SERVICE CHAPTER. THE PROPER PRELOAD IS 15 POUNDS WITH THE ARM EXTENDED AT A RIGHT ANGLE.
3. SHOULDER JOINT	A. SUPPORT BEARING, IF IT LOOSENS, REPLACE IT AS DESCRIBED IN SERVICE CHAPTER. B. MOTOR BEARING, MOTOR MUST BE REMOVED AND ITS SHAFT CHECKED FOR SIDE PLAY AS FOLLOWS: REMOVE COVER PLATES FROM UPPER ARM. SUPPORT UPPER ARM TO PREVENT ITS COLLAPSE DURING THE FOLLOWING STEPS. REMOVE ELECTRICAL CONNECTOR TO MOTOR. REMOVE MOTOR BY PULLING IT STRAIGHT BACK. CHECK TO SEE ANY BEARING WEAR: IF BEARING WEAR IS DISCOVERED, REPLACE IT. IF NO WEAR IS INDICATED PROCEED TO NEXT STEP. REPLACE MOTOR IN THE SAME ORIENTATION AS IT WAS ORIGINALLY. REASSEMBLE ARM IN REVERSE ORDER.

	C. IDLER SHAFT BEARINGS. REMOVE GEAR COVER PLATE. TRY TO MOVE PINION SIDEWAYS. ANY LATERAL PLAY INDICATES WORN BEARINGS SUPPORTING THE IDLER SHAFT, NECESSITATING REPLACEMENT OF THE IDLER SHAFT AND CARTRIDGE AS AN ASSEMBLY.
4. ELBOW JOINT	A. SUPPORT BEARING ATTEMPT TO ROCK THE FOREARM SIDEWAYS AT THE JOINT. IF THERE IS ANY PLAY, REPLACE THE BEARINGS. B. MOTOR BEARING REMOVE SIDE COVER PANEL FROM THE UPPER ARM. CHECK IT TO SEE IF THERE IS A PROBLEM. IF WEAR OF THE MOTOR BEARING IS INDICATED, REPLACE IT. C. INPUT PINION BEARINGS REMOVE SIDE COVER PANEL. CHECK IT TO BE SURE IF IT HAS ANY PROBLEM. IF WEAR OF THE MOTOR BEARING IS INDICATED, REPLACE IT. D. IDLER SHAFT BEARING CHECK IT. IF IT IS NEEDED, REPLACE IT.
5. WRIST JOINT	A. SUPPORT BEARING REMOVE GRIPPER IF MOUNTED ON WRIST ASSEMBLY. GRASP MOUNTING FLANGE OF WRIST ASSEMBLY AND ATTEMPT TO MOVE IT BACK AND FORTH IN A SIDEWAYS DIRECTION. ANY PLAY INDICATES WORN SUPPORT BEARINGS OR INSUFFICIENT PRELOAD. REPLACE IT. B. MOTOR BEARINGS REMOVE COVER PLATE ON SIDE OF FOREARM. CAREFULLY MOVE THE MOTOR SHAFT. ANY SIDE PLAY INDICATES WORN MOTOR BEARINGS. REPLACE IT.

	C. INPUT PINION BEARINGS DISASSEMBLE. CAREFULLY CHECK. ANY SIDEPLAY INDICATES A WORN INPUT PINION BEARING AND COMPLETE WRIST ASSEMBLY MUST BE REPLACED. IF NO BEARING WEAR IS INDICATED, REASSEMBLE IT. RECALIBRATE IT.

D. BACKLASH ADJUSTMENT

ITEM	DESCRIPTION
1. GENERAL	BACKLASH ADJUSTMENTS MAY BE MADE WITHOUT REMOVING ANY COVERS: ONLY ACCESS HOLE PLUGS MUST BE REMOVED.
2. WAIST JOINT	THE GEAR TRAIN IN THE WAIST JOINT IS PRELOADED. THEREFORE, ANY BACKLASH IN THIS JOINT INDICATES MAJOR WEAR AND MAY REQUIRE ASSEMBLY OR GEAR REPLACEMENT.
3. SHOULDER JOINT	BACKLASH ADJUSTMENT IS MADE THROUGH THREE HOLES ON TOP OF THE UPPER ARM. A. SPUR GEAR BACKLASH INSERT 1/8 INCH HEX KEY ONTO REAR ACCESS HOLE AND TURN SCREW ONE TURN COUNTER-CLOCKWISE. INSERT 1/8 INCH HEX KEY INTO FRONT ACCESS AND ROTATE SCREW CLOCKWISE, APPROXIMATELY 1/8 OF A TURN. RECHECK BACKLASH. IF IT IS STILL THERE, REPEAT THIS STEP UNTIL BACKLASH DISAPPEARS. INSERT 1/8 INCH HEX KEY INTO REAR ACCESS HOLE AND ROTATE CLOCKWISE UNTIL SCREW BOTTOMS LIGHTLY. IF BACKLASH IS STILL PRESENT, FOLLOW THESE STEPS TO ADJUST THE BEVEL GEARS. IF NO BACKLASH IS PRESENT AFTER SPUR GEAR ADJUSTMENT, DO NOT ADJUST BEVEL GEAR. B. BEVEL GEAR BACKLASH
4. ELBOW JOINT	A. ADJUST SPUR GEAR BACKLASH B. ADJUST BEVEL GEAR BACKLASH
5. WRIST JOINT	A. PINION GEARING BACKLASH USE THE TWO ACCESS HOLES ON THE UPPER SIDE AT THE FOREARM. INSERT A 5/64 INCH HEX KEY INTO RIGHT HOLE AND TURN SCREW 1/4 TURN COUNTERCLOCKWISE.

	INSERT 3/32 INCH HEX KEY INTO LEFT HOLE AND TURN SCREW APPROXIMATELY 1/4 TURN COUNTERCLOCKWISE. INSERT A 5/64 INCH HEX KEY INTO THE SAME HOLE AND TURN WORN SCREW COUNTERCLOCKWISE. RECHECK FOR BACKLASH. IF BACKLASH IS STILL PRESENT, REPEAT THIS STEP UNTIL BACKLASH DISAPPEARS. TIGHTEN SCREW CAREFULLY IN RIGHT HOLE AND LEFT HOLE IN THAT ORDER. B. INPUT GEARING BACKLASH TO ADJUST BACKLASH IN THE INPUT GEARING. USE THE TWO ACCESS HOLES ON THE FRONT OF THE FOREARM. REPEAT STEPS OF PINION GEARING BACKLASH: TURN THE WORN SCREW CLOCKWISE INSTEAD OF COUNTERCLOCKWISE.

E. ELECTRICAL HARNESS WEAR INSPECTION

DURING NORMAL OPERATION, THE ELECTRICAL HARNESS THAT PASSES THROUGH THE TRUNK, THE SHOULDER, AND INTO THE UPPER ARM UNDERGOES CONTINUAL FLEXING AND SHOULD BE INSPECTED FOR ANY POSSIBLE WEAR TO ITS PROTECTIVE SHEATHING. PROCEED AS FOLLOWS:

-REMOVE SHOULDER END-PLATE.
-EXAMINE PROTECTIVE SHEATH ON HARNESS FOR ANY EVIDENCE OF WEAR OR SHAFTING.
-REPLACE SHOULDER END-PLATE.

I. TROUBLESHOOTING AND SERVICE

A. TOOLS AND SPECIAL EQUIPMENT

1. STANDARD HAND TOOLS
2. MICROMETER
3. DEPTH GAUGE
4. OHMMETER
5. VOLTMETER
6. ALIGNMENT TOOL

B. GENERAL PRINCIPLES FOR TROUBLESHOOTING

THE FOLLWING PARAGRAPHS PROVIDE TROUBLESHOOTING TECHNIQUES TO KEEP A ROBOT IN PROPER OPERATING CONDITION WITH AN ABSOLUTE MINIMUM OF DOWNTIME. IT IS REQUIRED THAT THE USER HAVE AN AVAILABLE SPARE PARTS KIT SO HE CAN BEST FOLLOW THE METHOD DESCRIBED IN THE FOLLOWING:

1. A METHOD IS BASED ON THE FACT THAT LOGICAL FUNCTIONS ARE ISOLATED TO PHYSICAL BLOCKS. BECAUSE THESE PHYSICAL BLOCKS ARE MODULAR AND INTERHCANGEABLE, PROBLEMS MAYBE FOUND AND SOLVED BY REPLACING THE FAULTY PHYSICAL BLOCK. THE CONCEPT IS TO ISOLATE THE PROBLEM TO A LOCAL REPLACEABLE PHYSICAL BLOCK. A PHYSICAL BLOCK IS DEFINED AS BEING A DC CARD, SERVOMETER, HARNESS. ETC.. AFTER LOCALIZING THE FAULTY PART, IT CAN BE REPLACED WITH A PART FROM THE SPARE PARTS KIT.
2. ONCE HAVING UNDERSTOOD THE GENERAL METHOD OF REPLACING MODULES RATHER THAN COMPONENTS ON A MODULE, THE NEXT STEP IS TO UNDERSTAND THE METHOD OF ISOLATING PROBLEMS TO A MODULE. THIS PROCESS IS ACTUALLY ONLY A LOGICAL SEQUENCE BY WHICH A USER CAN DEDUCE WHERE THE SOURCE OF THE PROBLEM OCCURS. THIS METHOD CAN BE GENERALLY APPLIED WITHOUT KNOWING THE FUNCTION OF ANY MODULE OR THE ACTUAL SOURCE OF THE PROBLEM. THE TECHNIQUE IS TO DETERMINE WHERE THE PROBLEM IS, NOT WHAT THE PROBLEM IS. THEREFORE, THE FUNCTION OF THE BOARDS ARE NOT EXPLICITLY DESCRIBED: INSTEAD, ONLY THE TYPE OF LOGIC NEEDED TO LOCATE THE PROBLEM IS DESCRIBED.

C. CONCEPT OF INTERCHANGEABILITY

CERTAIN PARTS ARE INTERCHANGEABLE. AS SHOWN IN FIG. 4-2-3, THE USER CAN SEE THAT MANY OF THE PARTS CAN REPLACE OTHERS. ESSENTIALLY, THERE IS A SEPARATE CHANNEL FOR EACH JOINT OF THE PUMA. FOR EACH CHANNEL, EXCLUDING THE EXCEPTIONS NOTED ON THE FIGURE, ALL PARTS ARE EQUIVALENT. THIS FEATURE REDUCES PROBLEM ISOLATION TIME.

D. PUMA ROBOT CONTROL SYSTEM AND BLOCK DIAGRAM

TO PROCEED WITH THIS METHOD TROUBLESHOOTING A ROBOT, THE USERS MUST UNDERSTAND THE BLOCK DIAGRAM, AS SHOWN IN FIG. 4-2-3. THIS FIGURE SHOWS THE PUMA ROBOT BROKEN DOWN INTO ITS VARIOUS PHYSICAL BLOCKS. SOME BLOCKS AFFECT THE WHOLE ARM; OTHERS AFFECT ONLY ONE INDIVIDUAL JOINT. IT CAN BE DEDUCED THAT IF THE PROBLEM AFFECTS ALL JOINTS, ONE OF THESE COMMON ELEMENTS IS IN ERROR. THE SECOND FACT IS THAT IF ONLY ONE JOINT EXHIBITS A SYMPTOMATIC PROBLEM, IT IS LIKELY THAT ONE OF THE ELEMENTS WITHIN THE STRING OF ELEMENTS CONTROLLING THAT JOINT IS IN ERROR. THEREFORE, THE ELEMENT CAUSING THE PROBLEM MUST BE ISOLATED. THE NEXT STEP IS TO LOGICALLY DEDUCE WHICH ONE OF THE BLOCKS IS THE CAUSE OF THE PROBLEM. THIS PROCESS IS ACCOMPLISHED BY INTERCHANGING EQUIVALENT KNOWN GOOD PARTS FOR THOSE POSSIBLY FAULTY, AND NOTING THE EFFECTS. ALTERNATIVELY, IF A FAULTY BOARD IS INTERCHANGED INTO A KNOWN GOOD JOINT, AND IF THE KNOWN GOOD JOINT HAS DEVELOPED THE SAME FAULT, THIS IS POSITIVE PROOF THAT THE BOARD IS FAULTY.

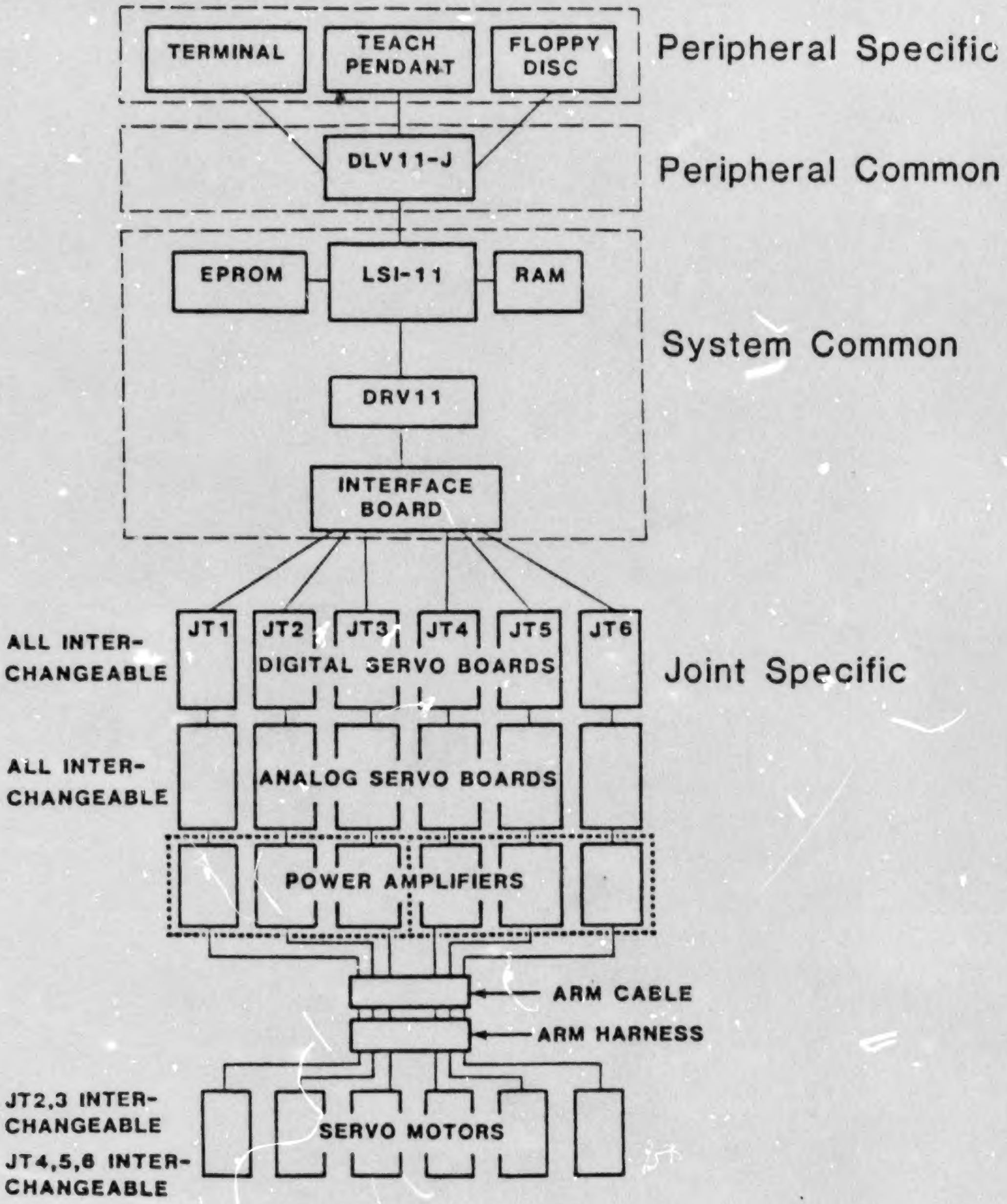

TERMINAL
TEACH PENDANT
FLOPPY DISC
Peripheral Specific
DLV11-J
Peripheral Common
EPROM
LSI-11
RAM
System Common
DRV11
INTERFACE BOARD
JT1
JT2
JT3
JT4
JT5
JT6
ALL INTER-CHANGEABLE
DIGITAL SERVO BOARDS
Joint Specific
ALL INTER-CHANGEABLE
ANALOG SERVO BOARDS
POWER AMPLIFIERS
ARM CABLE
ARM HARNESS
JT2,3 INTER-CHANGEABLE
JT4,5,6 INTER-CHANGEABLE
SERVO MOTORS

FIG. 4-2-3 CONTROL SYSTEM. BLOCK DIAGRAM.
(PUMA ROBOT)

E. PRETROUBLESHOOTING GUIDE

1. ENSURE ALL BOARDS ARE IN THEIR PROPER SLOT. BOARD POSITIONING BEGINS AT THE LEFT BACKPLANE SLOT, AS FOLLOWS:
   - A. DEC BACKPLANE
     - -PROCESSOR CARD
     - -RAM CARD
     - -UNIMATION EPROM
     - -SERIAL CARD (DLV11-J)
     - -SPACE
     - -ADAC INTERFACE (I/O)
     - -SPACE
     - -PARALLEL INTERFACE BOARD (DRV11)
     - (THE POSITIONING OF THE DRV11 IS NOT CRITICAL.)
   - B. UNIMATION BACKPLANE
     - -UNIMATION PARALLEL INTERFACE BOARD
     - -DIGITAL SERVO BOARD - JOINT 1
     - -DIGITAL SERVO BOARD - JOINT 2
     - -DIGITAL SERVO BOARD - JOINT 3
     - -DIGITAL SERVO BOARD - JOINT 4
     - -DIGITAL SERVO BOARD - JOINT 5
     - -DIGITAL SERVO BOARD - JOINT 6
     - -SPACE
     - -SPACE
     - -CLOCK TERMINATOR BOARD
     - -ANALOG SERVO BOARD - JOINT 1
     - -ANALOG SERVO BOARD - JOINT 2
     - -ANALOG SERVO BOARD - JOINT 3
     - -ANALOG SERVO BORAD - JOINT 4
     - -ANALOG SERVO BOARD - JOINT 5
     - -ANALOG SERVO BOARD - JOINT 6
     - -SPACE
     - -SPACE
     - -TWO PADDLE BOARDS (FRONT - JOINTS 1, 2, AND 3; REAR - JOINTS 4, 5, AND 6), CLAD SIDE TO RIGHT.
     - -ARM CABLE BOARD
2. MAKE SURE BOARDS ARE ALL SEATED SQUARELY IN THE BACKPLANE.
3. MAKE SURE ALL CABLES ARE PROPERLY CONNECTED.

F. TROUBLESHOOTING PROCEDURES

	SYMPTOM	POSSIBLE CAUSES	CORRECTIVE ACTION
1.	POWER ON ERROR	NO LIGHT FRONT PANEL AFTER SWITCH IS TURNED ON. NO FAN MOTION AFTER SWITCH IS TURNED ON.	CHECK PLUG AND FUSE. BURNT OUT LIGHT. CHECK AC POWER AT TERMINAL BLOCK. CHECK AC AT FAN CONNECTOR WITH VOLTMETER.
2.	INITIALIZATION	NO TERMINAL RESPONSE OR GARBLED MESSAGE ON TERMINAL.	ATTEMPT TURNING TERMINAL OFF, THEN ON AGAIN. PLUG TERMINAL INTO AC POWER. PLUG TERMINAL CABLE INTO APPROPRIATE PLACES IN TERMINAL AND CONTROLLER. ENSURE CORRECT BAUD RATE FOR CRT TERMINAL. ENSURE CORRECT BAUD RATE FOR TTY TERMINAL. ENSURE SWITCH SETTINGS ON TERMINAL ARE CORRECT. ENSURE BLACK CONNECTOR (MARKED J3) IS PLUGGED INTO J3 OF SERIAL CARD. ENSURE BAUD RATES SELECTED CORRECTLY ON SERIAL CARD. ENSURE ALL DEC BOARDS ARE INSERTED IN PROPER ORDER. ENSURE JUMPERS ON ALL DEC BOARDS ARE SET CORRECTLY: EPROM JUMPERS, SERIAL BOARD, PARALLEL BOARD. POWER SUPPLY PROBLEMS. MEASURE AT ANY FRONT PANEL CONNECTOR. ATTEMPT REPLACING TERMINAL WITH A NEW ONE.

SYMPTOM	POSSIBLE CAUSES	CORRECTIVE ACTION
	NO INITIALIZATION MESSAGE	NUMERIC OUTPUT (ODT) AND/OR RED LIGHT ON CLOCK TERMINATOR BOARD OFF. A. TOGGLE REAR SWITCH ON CLOCK/TERMINATOR BOARD TO REINITIALIZE VAL. B. CHECK 10-PIN CONNECTORS TO CLOCK/TERMINATOR BOARD. FRONT PANEL TO BOTTOM ON CLOCK/TERMINATOR BOARD. DEC BACKPLANE TO TOP ON CLOCK/TERMINATOR BOARD. C. FRONT SWITCH SHOULD BE AWAY FROM FRONT PANEL ON CLOCK/TERMINATOR BOARD. ATTEMPT REPLACING: A. CLOCK/TERMINATOR BOARD. B. VAL CHIPS OR EPROM BOARD. C. SERIAL BOARD. CHECK THAT THERE ARE NO SPACES IN BACKPLANE BETWEEN PROM BOARD AND SERIAL BOARD.
3. POST INITIALIZATION ERRORS	ADC DEAD, JTN (1-6) OR SERVO DEAD, JTN.	REPLACE NTH DIGITAL SERVO BOARD. REPLACE CLOCK/TERMINATOR BOARD. REPLACE UNIMATION INTERFACE BOARD.
	JOINT N OUT OF RANGE	IF JOINT 4. 5. OR 6 IS OUT OF RANGE, MOVE JOINT MANUALLY SO THAT IT IS IN ITS NORMAL OPERATING RANGE. PLACE ARM IN READY POSITION AND CHECK POTENTIOMETER VOLTAGE READINGS BY RUNNING POTCAL.

		REPLACE UNIMATION INTERFACE BOARD. ENSURE ARM CABLE CARD IS SEATED PROPERLY IN BACKPLANE. REMOVE ARM CABLE AT ARM AND CHECK FOR 5V AT ARM END OF ARM CABLE. IF FAULTY, REPLACE ARM CABLE. DISCONNECT CONNECTOR TO SERVOMETER IN ERROR AND CHECK PINS 8 AND 11 FOR 5V. (A) IF 5V IS PRESENT, SERVOMETER IS IN ERROR. REPLACE SERVOMETER. (B) CHECK FOR OPENS IN ARM HARNESS. REPLACE IF FAULTY.
	PROM ERROR.	CHECK THAT ALL EPROMS ARE SEATED PROPERLY IN SOCKET.
	MEMORY ERROR.	CAUSED BY FAULTY RAM MEMORY. REPLACE RAM BOARD.
	NO MESSAGES.	ATTEMPT RESTARTING BY TURNING POWER OFF AND ON ON AGAIN. CHECK PARALLEL BOARD JUMPERS.
4. HIGH POWER TURN-ON ERROR	ONE JOINT MOVES WHEN TURNING ARM POWER ON.	FAULTY ENCODER. (A) PHYSICALLY DAMAGED INSIDE OF MOTOR. (B) WIRING FROM ENCODER TO CONTROLLER FAULTY. CHECK CONNECTORS OR MOTOR FOR LOOSE PINS. FAULTY POWER AMPLIFIER. ADJUSTMENTS ON ANALOG BOARD NOT CORRECT. AN OPEN CIRCUIT IN FEEDBACK LOOP FROM MOTOR CABLE CARD TO ANALOG BOARD.

	ALL JOINTS MOVE WHEN TURNING ARM POWER ON.	REPLACE FAULTY BLOCK. CHECK PLUS AND MINUS 40V AT POWER SUPPLY.
	JOINT DRIFTS OR GOES LIMP WHEN NOT GIVEN COMMAND.	REPLACE FAULTY BLOCK.
		NOTE: BEFORE PRESSING ARM POWER ON BUTTON, OPERATOR AND ALL OTHER PERSONNEL AND OBSTRUCTIONS MUST BE CLEAR OF THE ROBOT ARM MAXIMUM REACH. ARM BEHAVIOR MAY BE UNPREDICTABLE IF A MALFUNCTION OCCURS.
5. TEACH PENDANT FUNCTIONAL ERROR	FAULTY TEACH PENDANT: NO MESSAGES ON DISPLAY.	CHECK SERIAL CARD CONNECTOR (J0). FAULTY TEACH PENDANT AND/OR CABLE. CHECK 5V, 12V, AND -12V AT OUTPUT CONNECTOR ON CONSOLE. REPLACE SERIAL BOARD (DRV11-J).
	FAILURE TO MOVE IN FREE MODE.	CHECK THAT BRAKES RELEASE IN FREE MODE FOR JOINTS 1, 2, AND 3. REPLACE CLOCK/TERMINATOR BOARD.
	NO RESPONSE IN JOINT MODE.	REPLACE FAULTY BLOCK.
	JOINT MOVES OUT OF CONTROL IN JOINT MODE.	REPLACE FAULTY BLOCK.
	GRIPPER CONTROL NOT OPERATIVE.	CHECK IF AIR IS ON. CHECK TEACH PENDANT IN JOINT, WORLD, OR TOOL MODE. CHECK FOR 24V AT PINS 8 AND 12 ON J8 IN ARM. CHECK FOR 24V PINS 9 AND 12 ON J8 IN ARM (HAND OPEN), AND PINS 10 AND 12 ON J8 (HAND CLOSED).

		(A) CHECK VOLTAGE AT CABLE CARD. IF VOLTAGES ARE CORRECT, REPLACE AIR SOLENOID IN ARM. (B) IF VOLTAGES ARE INCORRECT, REPLACE CABLE CARD ON UNIMATION INTERFACE BOARD. REPLACE TEACH PENDANT.
6. CALIBRATION PROBLEMS	COMPUTER MODE DISABLED.	PRESS COMP BUTTON ON TEACH PENDANT. REENTER CALIBRATE COMMAND.
	NO ZERO REFERENCE JOINT N.	GO TO SOCKET 4E ON DIGITAL BOARD AND REMOVE JUMPER. REPLACE DIGITAL SERVOBOARD. REPLACE FAULTY BLOCK.
	ARM DOES NOT RESPOND.	TURN ARM POWER ON. REPLACE FAULTY BLOCK.
7. OPERATING ERRORS	READY POSITION NOT CORRECT FOR JOINT N.	ATTEMPT CALIBRATING AGAIN. RUN POTCAL. REPLACE UNIMATION INTERFACE BOARD. REPLACE JOINT N MOTOR (MUST RE-PROM).
	TEACH PENDANT WORLD OR TOOL MOTIONS NOT STRAIGHT.	PERFORM CALIBRATE COMMAND. USER PROMS NOT CORRECT FOR MACHINE. RUN POTCAL AND USE OVERLAY. STRAIGHT LINE MOVES ARE LIMITED BY JOINT VELOCITY LIMITATIONS.
	ARM DOES NOT REPEAT TO PROGRAMMED POSITIONS.	DETERMINE IF THIS IS AN ALL JOINT PROBLEM OR AN INDIVIDUAL JOINT PROBLEM. REPLACE FAULTY BLOCK.

	CLOCK OVERRUN ERROR.	RESTART VAL. REPLACE CLOCK/TERMINATOR BOARD. CHECK THAT NO EXTERNAL VOLTAGE IS IN CONTACT WITH ARM.
	INVALID SOLUTION.	DUE TO AN IMPROPERLY PROGRAMMED POINT (ESPECIALLY FOR STRAIGHT LINE MOVES). REPROGRAM POINT. INSERT AN INTERMEDIARY POINT THAT GENERATES A GOOD SOLUTION.
	TIMEOUT ERROR.	CAUSED BY A JOINT NOT MOVING WITH A 4-SECOND INTERVAL, PROBABLY DUE TO AN OBSTRUCTION. CHECK BRAKES ON JOINT SPECIFIED IN ERROR MESSAGE. CHECK ADJUSTMENT OF ANALOG BOARD FOR THE JOINT IN QUESTION. CHECK ENCODERS ON JOINT SPECIFIED IN ERROR MESSAGE. REPLACE FAULTY BLOCK.
	NOT CALIBRATED.	USE CALIBRATE COMMAND. IF NO ZERO REFERENCE ERROR MESSAGE, REFER TO SYMPTOM, CALIBRATION PROBLEMS, STEP B.
	SERVO/GEAR NOISE.	

G. SERVICE

THE FOLLOWING ITEMS PROVIDE PROCEDURES FOR REPLACING SUBASSEMBLIES AND PARTS TO KEEP THE PUMA ROBOT IN PROPER OPERATION.

WARNING: DO NOT REPLACE COMPONENTS OR MAKE ADJUSTMENTS TO A ROBOT WHEN ELECTRICAL OR PNEUMATIC POWER IS TURNED ON.

1. WRIST REPLACEMENT

THE PROCESSES OF WRIST REPLACEMENT ARE AS FOLLOWS. THE PARTS AND SCREW LOCATIONS ARE SHOWN IN FIG. 4-2-4.

CAUTION: BEFORE REMOVING THE WRIST ASSEMBLY, NOTE ITS ORIENTATION RELATIVE TO THE FOREARM SO THAT REASSEMBLY WILL BE CORRECT.

A. EXTEND ARM TO STRAIGHT-OUT POSITION.
B. REMOVE OUTER LINK ACCESS PLATE.
C. MANUALLY ROTATE WRIST SO THAT JOINT 5 AND JOINT 6 COUPLINGS ARE VISIBLE THROUGH ACCESS HOLE.
D. THROUGH ACCESS OPENING OF OUTER LINK. ROTATE JOINT 5 AND JOINT 6 SHAFTS SO THAT COUPLING SCREWS ARE VISIBLE THROUGH ACCESS HOLE.
E. LOOSEN JOINT 5 AND JOINT 6 COUPLING SCREWS.
F. REMOVE FOUR WRIST SCREWS; THEN SLIDE WRIST FROM ARM.
G. INSTALL NEW WRIST IN REVERSE ORDER OF REMOVAL.

CAUTION: ASSURE THAT JOINT 5 AND JOINT 6 SHAFTS ARE NOT IN TOUCH.

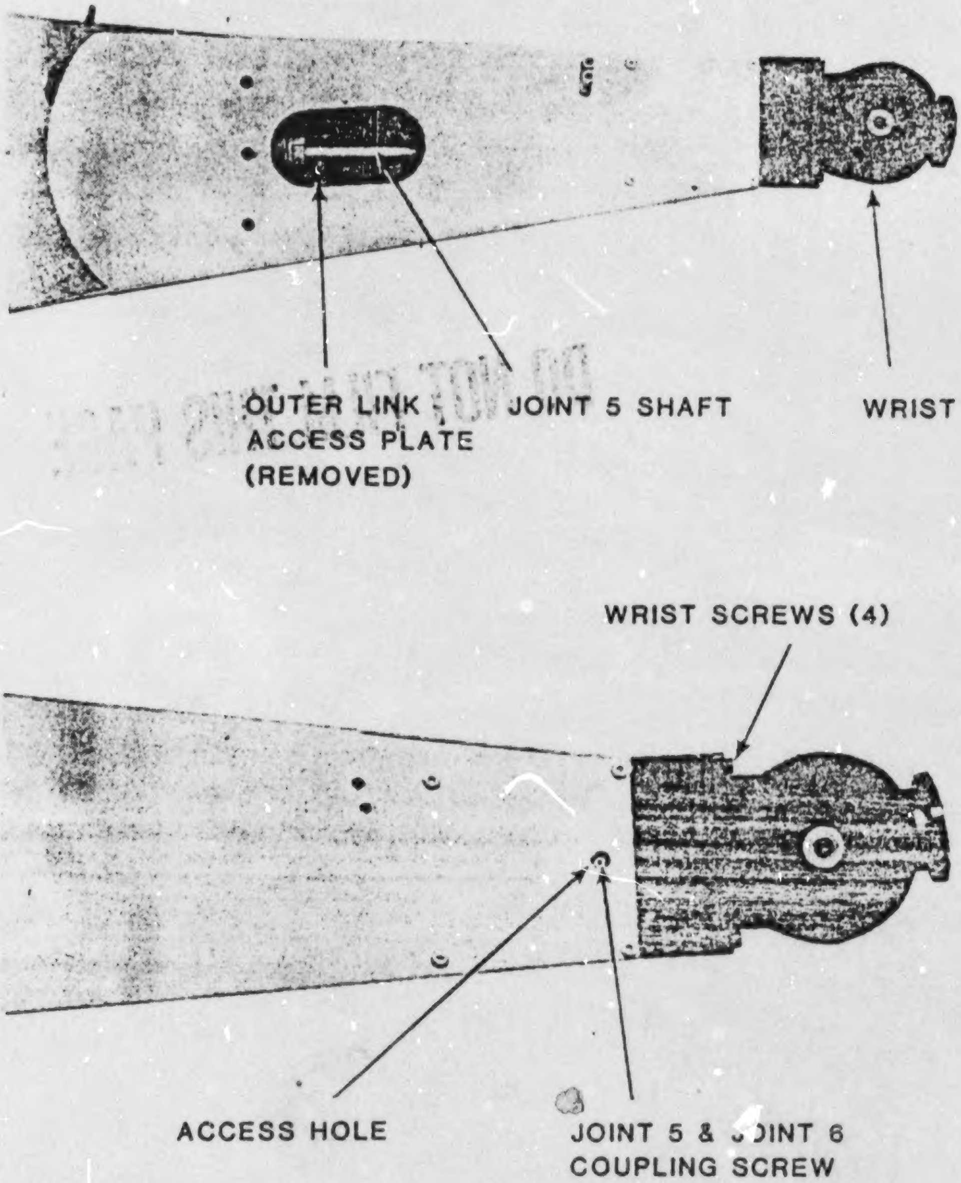

OUTER LINK
ACCESS PLATE
(REMOVED)
JOINT 5 SHAFT
WRIST
WRIST SCREWS (4)
ACCESS HOLE
JOINT 5 & JOINT 6
COUPLING SCREW

FIG. 4-2-4 Wrist Replacement

2. OUTER LINK REPLACEMENT

THE PROCESSES OF OUTER LINK REPLACEMENTS ARE AS FOLLOWS: (REFER TO FIG. 4-2-4, 4-2-5, AND 4-2-6 FOR PARTS AND SCREW LOCATIONS).

A. REMOVE INNER LINK ACCESS COVER.
B. UNPLUG INNER MOTOR CONNECTORS.
C. DISCONNECT AIR LINES FROM OUTER LINK TO PNEUMATIC VALVE.
D. THROUGH INNER LINK ACCESS OPENING, ROTATE JOINT 3 SHAFT SO THAT COUPLING SCREWS ARE VISIBLE THROUGH JOINT 3 ACCESS HOLE.
E. LOOSEN JOINT 3 COUPLING SCREWS.
F. UNPLUG JOINT 3 MOTOR CONNECTOR.
G. REMOVE FOUR MOTOR SCREWS; THEN REMOVE JOINT 3 MOTOR.
H. REMOVE SIX INPUT AND IDLER CARTRIDGE SCREWS THROUGH INNER LINK ACCESS HOLE.
I. USING A DRIFT PIN AND HAMMER, TAP OUT AND REMOVE IDLER AND INPUT CARTIDGES, RESPECTIVELY.
J. REMOVE THREE JOINT 3 RETAINER SCREWS; THEN REMOVE RETAINER.
K. TAP JOINT 3 MACHINED FACE OF OUTER LINK CASTING NEW OUTER LINK.
L. CALCULATE SHIM THICKNESS AS FOLLOWS:
   1. MEASURE DIMENSION FROM LINK TO INNER RACE OF BEARING.
   2. MEASURE DIMENSION OF INSIDE LIP OF RETAINER.
   3. SUBTRACT LINK-TO-INNER RACE DIMENSION FROM RETAINER LIP DIMENSION.

FOR EXAMPLE:
.040 RETAINER LIP DIMENSION
- .010 LINK-TO-INNER RACE DIMENSION
.030 SHIM SIZE REQUIRED

   4. PEEL SHIM TO SIZE, AND ADD IT BEHIND LINK RETAINER.
   5. INSTALL PARTS IN REVERSE ORDER OF REMOVAL.

NOTE: THE PERFORMANCE OF BACKLASH CHEEKS AND ADJUSTMENTS ARE NECESSARY.

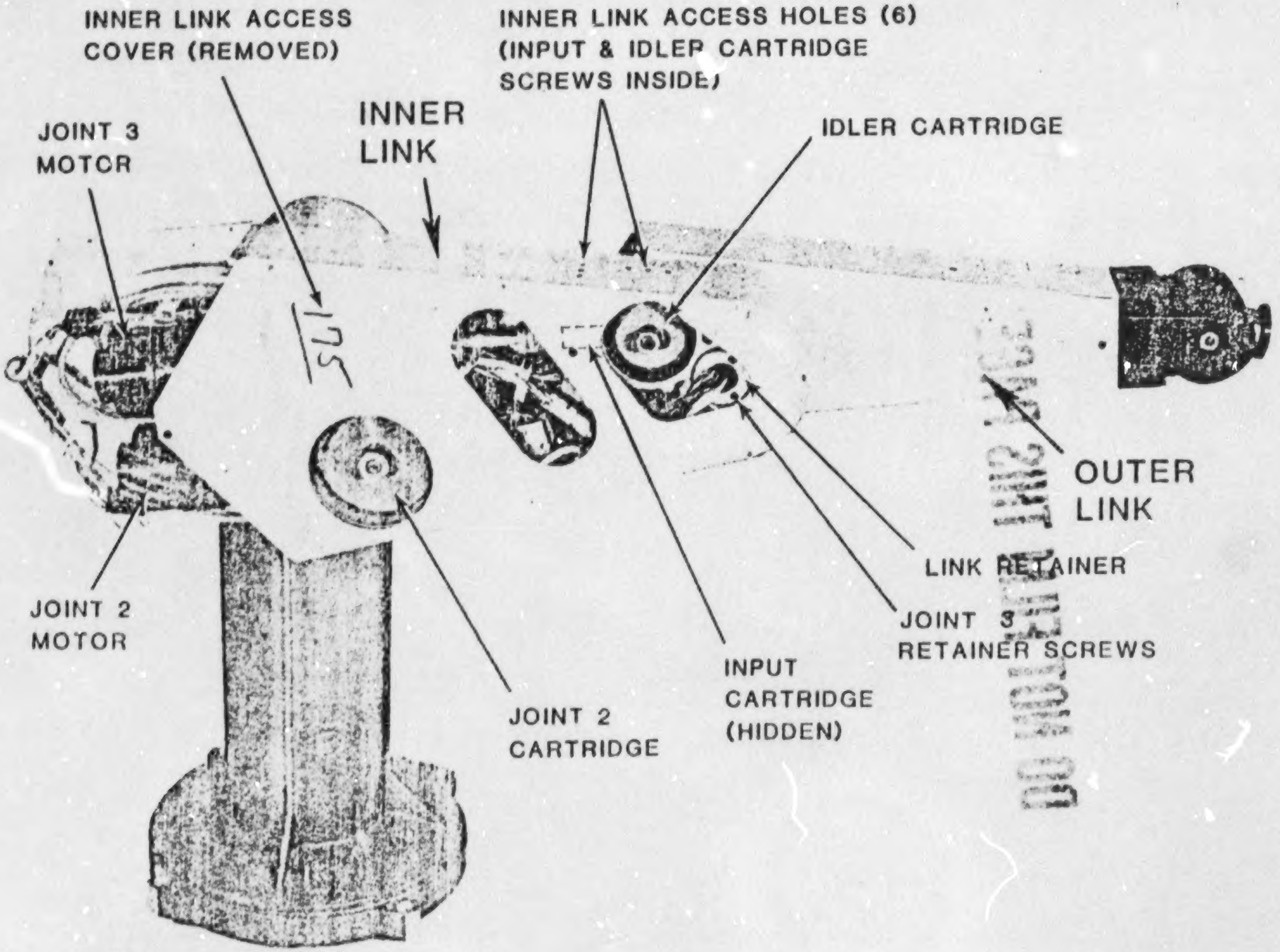

INNER LINK ACCESS COVER (REMOVED)
INNER LINK ACCESS HOLES (6) (INPUT & IDLER CARTRIDGE SCREWS INSIDE)
INNER LINK
JOINT 3 MOTOR
IDLER CARTRIDGE
175
OUTER LINK
LINK RETAINER
JOINT 3 RETAINER SCREWS
JOINT 2 MOTOR
INPUT CARTRIDGE (HIDDEN)
JOINT 2 CARTRIDGE

FIG. 4-2-5 PUMA Link Replacement

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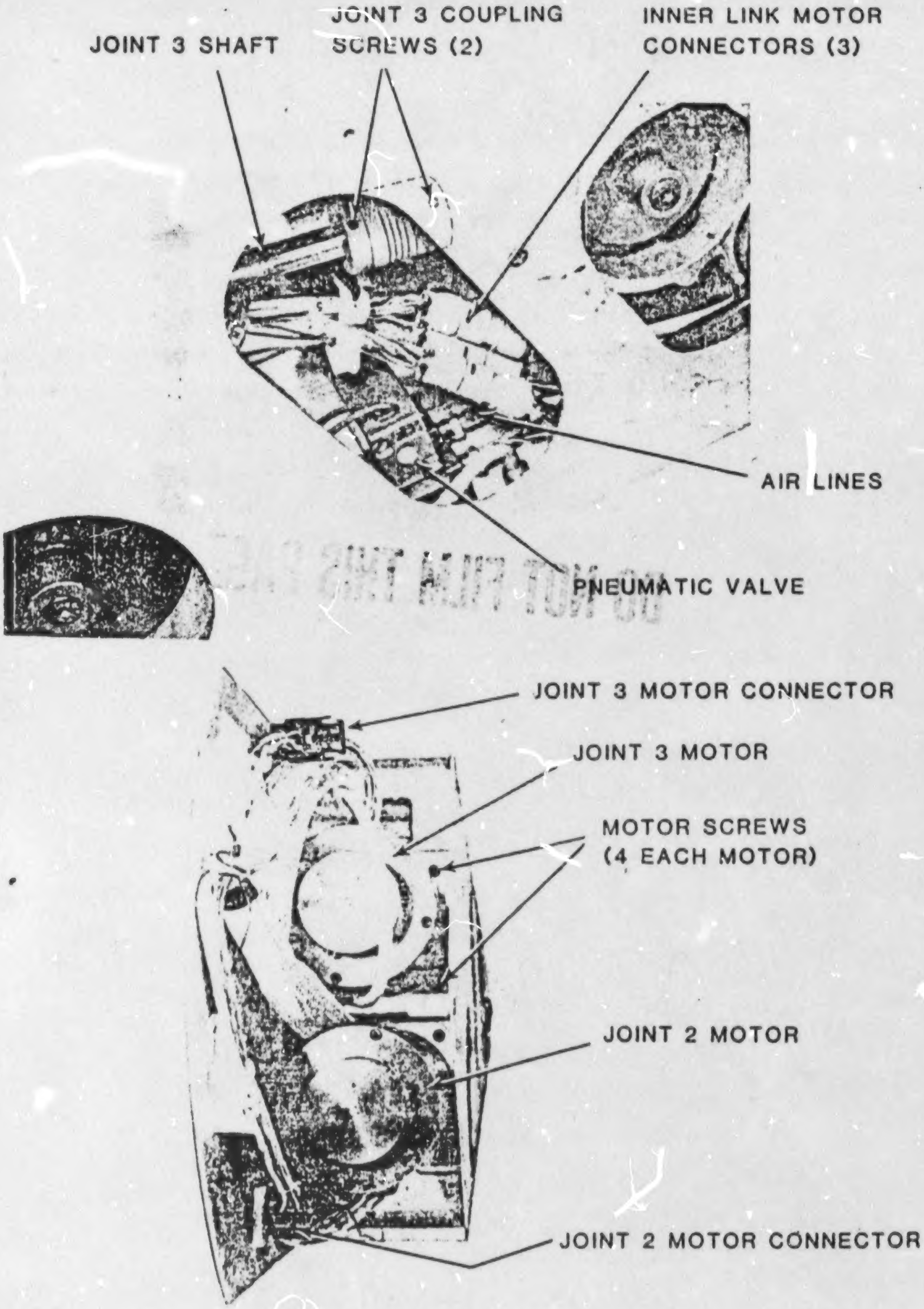
JOINT 3 SHAFT
JOINT 3 COUPLING SCREWS (2)
INNER LINK MOTOR CONNECTORS (3)
AIR LINES
PNEUMATIC VALVE
JOINT 3 MOTOR CONNECTOR
JOINT 3 MOTOR
MOTOR SCREWS (4 EACH MOTOR)
JOINT 2 MOTOR
JOINT 2 MOTOR CONNECTOR

FIG. 4-2-6 Inner Link Detail

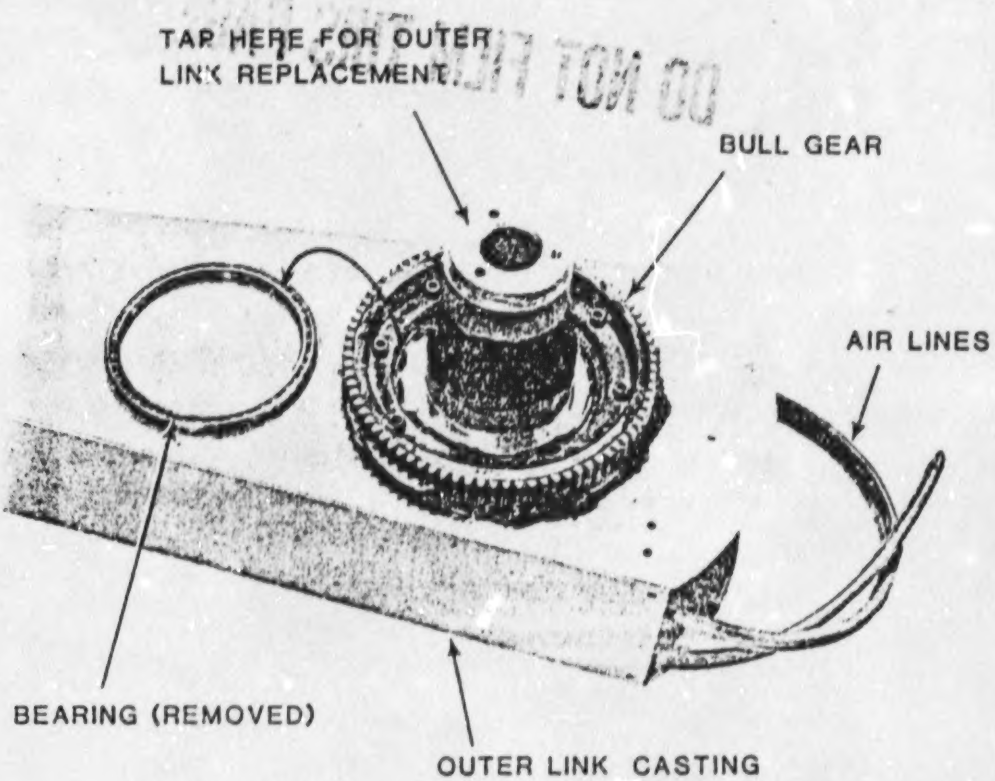
TAP HERE FOR OUTER LINK REPLACEMENT.
BULL GEAR
AIR LINES
BEARING (REMOVED)
OUTER LINK CASTING

FIG. 4-2-7 Outer Link Detail

3. INNER LINK REPLACEMENT

REFER TO FIGURES 4-2-5, 4-2-6, 4-2-7, 4-2-8, AND 4-2-11 FOR PARTS AND SCREW LOCATIONS, THE PROCEDURES TO REPLACE THE INNER LINK AS FOLLOWS:

A. REMOVE INNER LINK ACCESS COVERS.
B. UNPLUG
C. REMOVE JOINT 3 AND JOINT 2 MOTORS.
D. REMOVE OUTER LINK.
E. CUT AND REMOVE AIR LINES FROM SOLENOID.
F. REMOVE SHOULDER ACCESS COVER.
G. PULL ELECTRICAL HARNESS THROUGH SHOULDER ACCESS OPENING.
H. REMOVE FOUR JOINT 2 RETAINER SCREWS; THEN REMOVE RETAINER.
I. REMOVE JOINT 2 BULL GEAR COVER.
J. USING A DRIFT PIN AND HAMMER, TAP OUT AND REMOVE JOINT 2 CARTRIDGE.
K. TAP JOINT 2 MACHINED FACE OF INNER LINK CASTING FROM SHOULDER CASTING.
L. LUBRICATE BULL GEAR AND BEARINGS; THEN INSTALL NEW INNER LINK.
M. CALCULATE SHIM THICKNESS AS FOLLOWS:

1. MEASURE DIMENSION OF INSIDE LIP OF RETAINER.
2. MEASURE DIMENSION OF INSIDE LIP OF RETAINER.
3. SUBTRACT LINK-TO-INNER RACE DIMENSION FROM RETAINER LIP DIMENSION.

FOR EXAMPLE: .040 RETAINER LIP DIMENSION
- .010 LINK-TO-INNER RACE DIMENSION
.030 SHIM SIZE REQUIRED

4. PEEL SHIM TO SIZE, AND ADD IT BEHIND LINK RETAINER.
5. INSTALL PARTS IN REVERSE ORDER OF REMOVAL.

NOTE: PERFORM NECESSARY BACKLASH CHECKS AND ADJUSTMENTS.

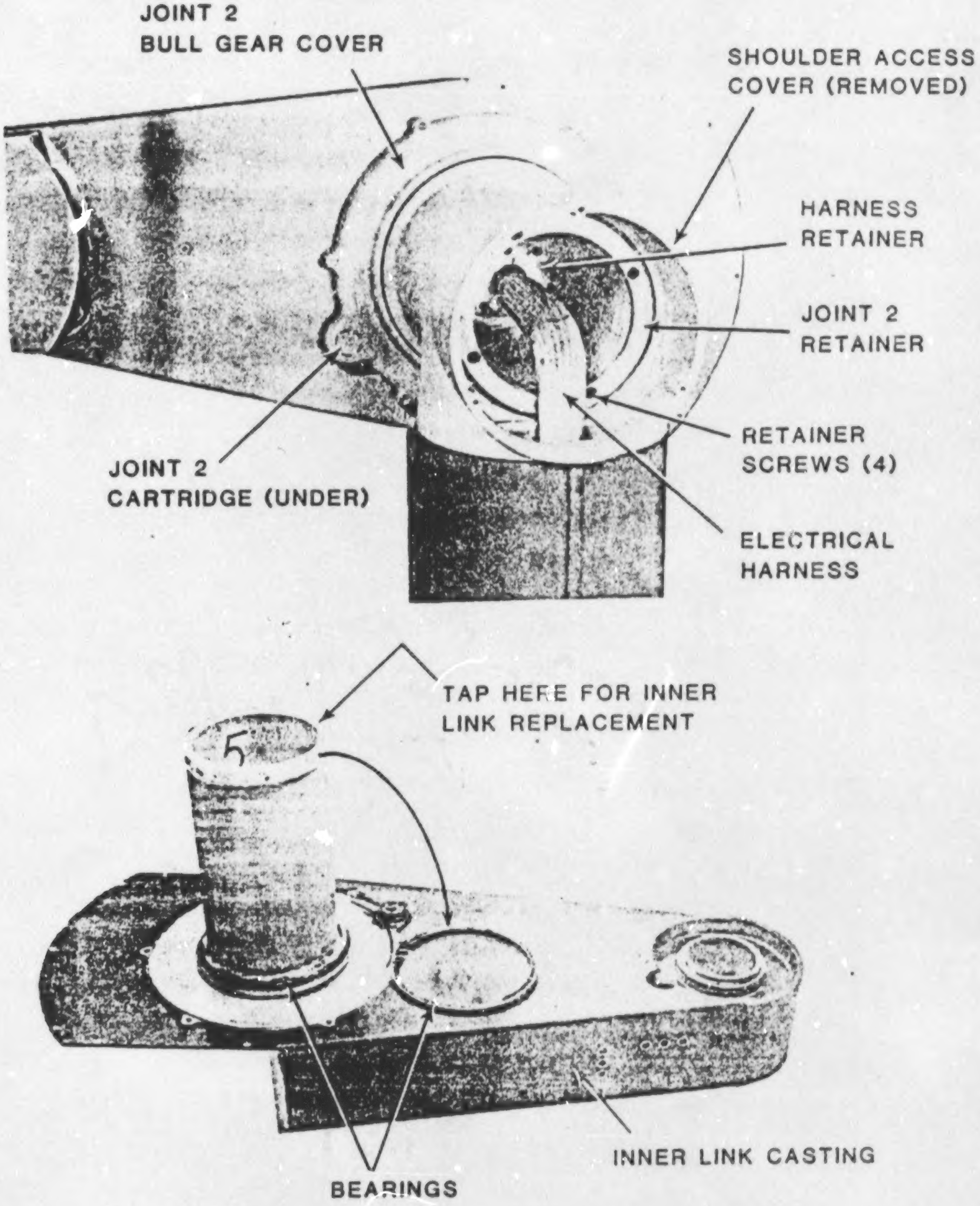
JOINT 2
BULL GEAR COVER
SHOULDER ACCESS
COVER (REMOVED)
HARNESS
RETAINER
JOINT 2
RETAINER
RETAINER
SCREWS (4)
ELECTRICAL
HARNESS
JOINT 2
CARTRIDGE (UNDER)
TAP HERE FOR INNER
LINK REPLACEMENT
5
INNER LINK CASTING
BEARINGS

FIG. 4-2-8 INNER LINK REPLACEMENT

4. INNER LINK MOTOR REPLACEMENT

THE PROCEDURES OF REPLACING INNER LINK MOTOR ARE AS FOLLOWS (REFER TO FIG. 4-2-5 AND 4-2-6):

A. REMOVE INNER LINK ACCESS COVER.
B. UNPLUG JOINT 2 MOTOR CONNECTOR.
C. REMOVE JOINT 2 MOTOR SCREWS, THEN REMOVE MOTOR.
D. INSTALL PARTS IN REVERSE ORDER OF REMOVAL.

NOTE: PERFORM NECESSARY BACKLASH CHECKS AND ADJUSTMENTS.

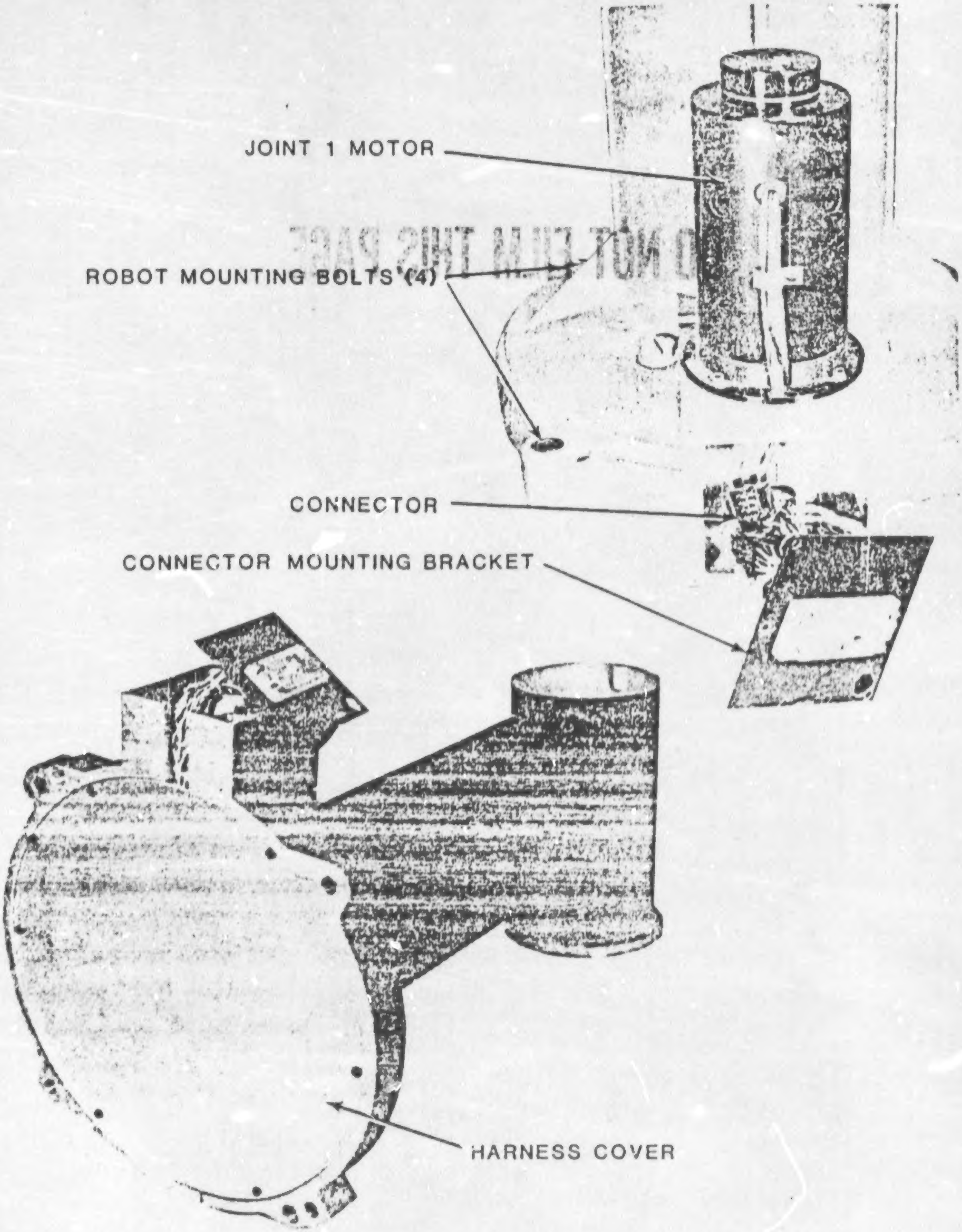
JOINT 1 MOTOR
ROBOT MOUNTING BOLTS (4)
CONNECTOR
CONNECTOR MOUNTING BRACKET
HARNESS COVER

FIG. 4-2-9 JOINT 1 ASSEMBLY AND MOTOR REPLACEMENT

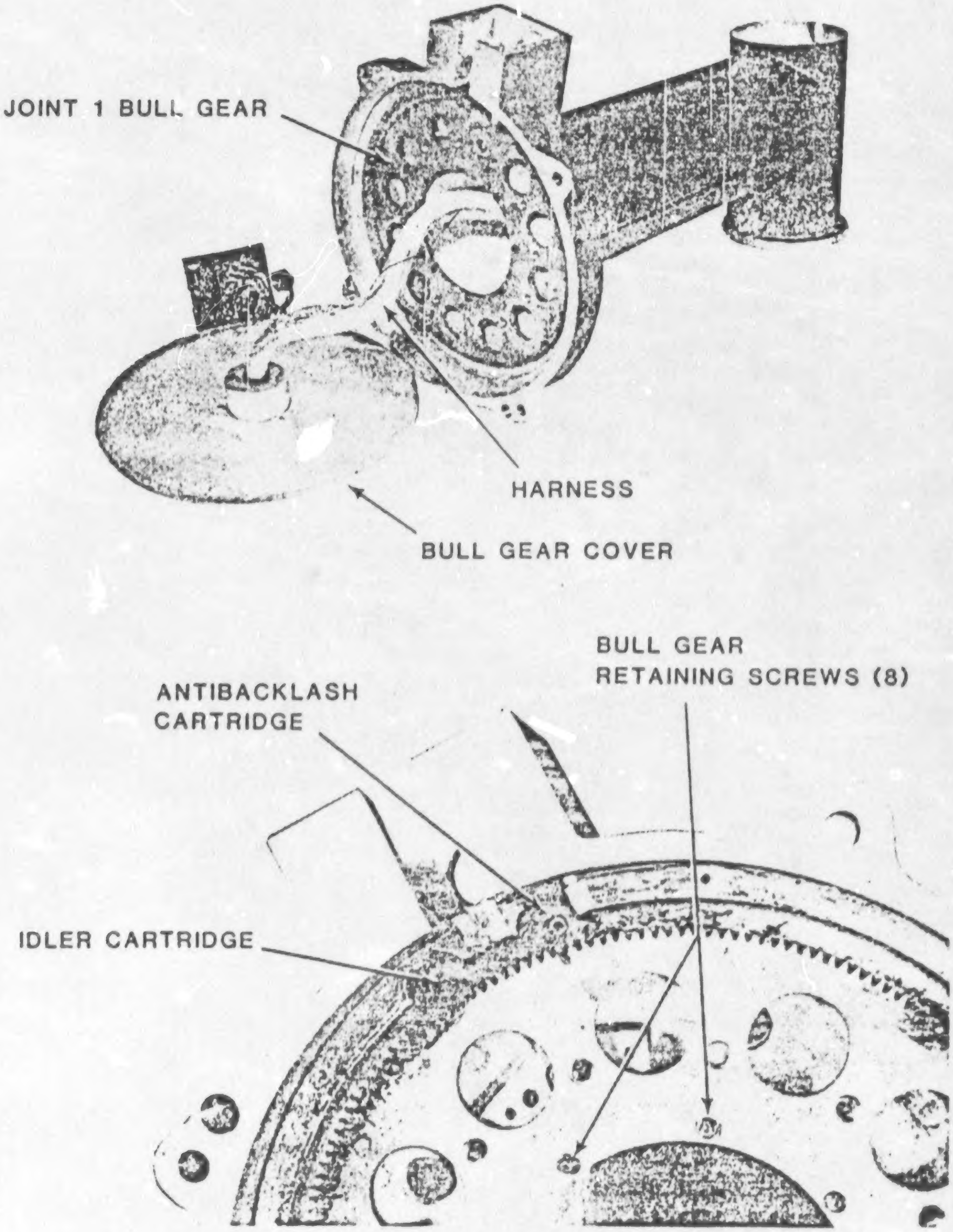
JOINT 1 BULL GEAR
HARNESS
BULL GEAR COVER
BULL GEAR
RETAINING SCREWS (8)
ANTIBACKLASH
CARTRIDGE
IDLER CARTRIDGE

FIG. 4-2-10 JOINT 1 ASSEMBLY

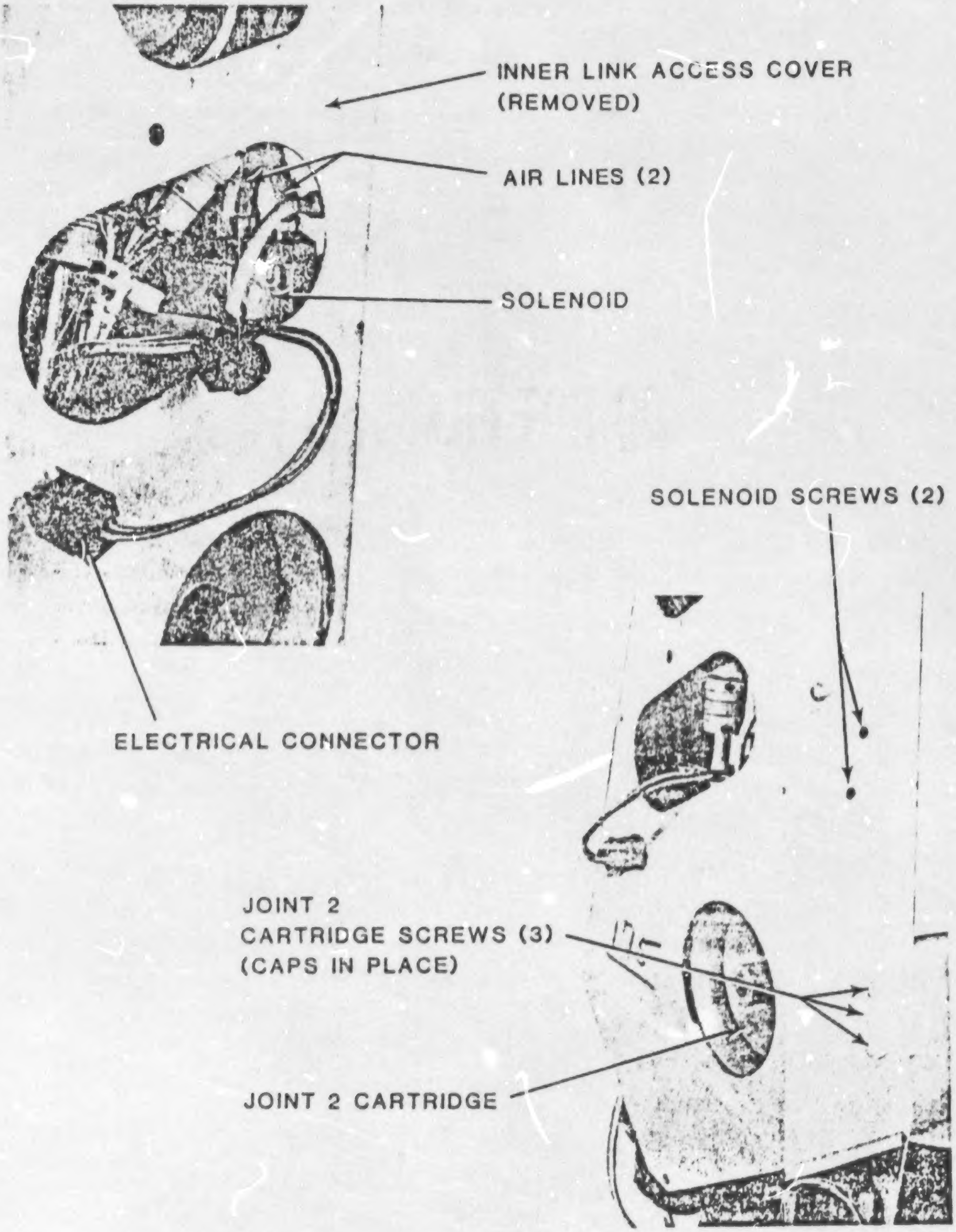
INNER LINK ACCESS COVER
(REMOVED)
AIR LINES (2)
SOLENOID
ELECTRICAL CONNECTOR
SOLENOID SCREWS (2)
JOINT 2
CARTRIDGE SCREWS (3)
(CAPS IN PLACE)
JOINT 2 CARTRIDGE

FIG. 4-2-11 SOLENOID REPLACEMENT

LESSON PLAN #2

UNIT 4--MAINTENANCE AND SERVICE

ASSIGNMENT SHEET 1

AFTER READING THE INFORMATION SHEETS (IS4-2-1, IS4-2-2) PROVIDED, COMPLETE THE FOLLOWING QUESTIONS IN WRITING OR AS REQUESTED BY YOUR INSTRUCTOR.

1. HOW DO YOU GET THE GEAR LUBRICATION IN THE SHOULDER JOINT OF THE PUMA ROBOT?

2. IF THE POWER SWITCH IS TURNED ON, AND THERE ARE NO LIGHTS ON THE FRONT PANEL, WHAT SHOULD YOU DO?

3. WHAT ARE THE POSSIBLE CAUSES IF POST INITIALIZATION HAPPENS?

4. DESCRIBE THE PROCEDURES OF REPLACING A INNER LINK MOTOR ON THE PUMA ROBOT.

5. WHAT POSSIBLE CAUSES COULD HAPPEN IF THE TEACH PENDANT FUNCTIONS IMPROPERLY?

SYLLABUS SHEET FOR LESSON 3
ROBOT SERVICE AND REPAIR

UNIT #4 SERVICE & REPAIR

SAFETY

LESSON OBJECTIVE--UPON COMPLETION OF THIS LESSON THE STUDENT SHOULD BE ABLE TO:

1. VERBALLY DESCRIBE THE SAFETY IN ROBOT APPLICATION.
2. VERBALLY EXPLAIN THE FUNCTION OF ROBOT SENSORS.
3. VERBALLY DESCRIBE THE ROBOT MAINTENANCE SAFETY.

TEACHING AIDS:

1. H4-3-1 SYLLABUS
2. T4-3-1 SAFETY
3. T4-3-2 SENSOR SAFETY
4. T4-3-3 ROBOT MAINTENANCE SAFETY

INFORMATIONAL ASSIGNMENT:

1. IS4-3-1 PERSONNEL SAFETY
2. IS4-3-2 ROBOT SAFETY
3. IS4-3-3 MAINTENANCE SAFETY
   ANSWER THE QUESTIONS FOUND ON INFORMATION SHEETS
1. AS4-3-1 SAFETY

REFERENCES:

ZIANKOSKI, S.& HSIE A., PERSONNEL SAFETY & ROBOT SAFETY, STATE UNIVERSITY OF NEW YORK COLLEGE OF TECHNOLOGY, 1982.

SAFFORD, EDWARD L., THE COMPLETE HANDBOOK OF ROBOTICS, THE TAB BOOK CO.,1976.

STEP 1- INTRODUCTION FOR PREPARATION OF THE STUDENT:

A SAFE AND GOOD WORKING ENVIRONMENT HAVE BEEN IDENTIFIED AS ESSENTIAL COMPONENTS IN ALL ACCIDENT PREVENTION PROGRAMS.

IN THIS LESSON PLAN, THE STUDENT WILL LEARN AND UNDERSTAND THE REGULATIONS OF PERSONNEL SAFETY AND ROBOT SAFETY USED ON ROBOT WORKING AREA.

LESSON SUMMARY AND REVIEW:

1. WHAT WILL WE USUALLY DO WHEN WE ARE PRESSING ARM POWER ON A BUTTON OF A ROBOT?

2. LIST FOUR ITEMS THAT KEEP THE OPERATOR AWAY FROM DANGER OF RECEIVING ELECTRICAL SHOCKS OR TRIPPING OVER LOOSE CABLES.

3. WHAT DO WE USUALLY USE TO PROTECT THE ROBOT FROM COLLISIONS WITH OBJECTS AND PERSONS WHO WANDER IN THE ROBOT OPERATION AREA?

4. WHAT CONDITIONS ARE TO BE MONITORED BY USING THE INTERNAL SENSORS?

5. ______________ ARE USED TO PROTECT THE ROBOT FROM CORROSIVE MATERIALS WHICH COULD CAUSE DETERIORATION.

PERSONNEL SAFETY

I. BEFORE PRESSING ARM POWER ON BUTTON OF A ROBOT. THE OPERATOR AND ALL OTHER PERSONNEL OBSTRUCTIONS MUST BE CLEAR OF THE ROBOT'S ARM MAXIMUM REACH. ARM BEHAVIOR MAY BE UNPREDICTABLE WHEN ARM POWER IS TURNED ON IF A MALFUNCTION OCCURS.
NOTE: AREA OF ARM REACH MUST BE DISTINCTLY MARKED.

II. WHEN PRESSING ARM POWER ON BUTTON, KEEP OTHER HAND NEAR ARM POWER OFF BUTTON FOR EMERGENCY SHUTDOWN IF NECESSARY.

III. ARM PROCEEDS DIRECTLY TO BEGINNING OF PROGRAM FOLLOWING A RESTART/RUN SEQUENCE. BEWARE OF OBSTACLES.

IV. EMERGENCY STOP CAN BE ADJUSTED TO MECHANICALLY RESTRICT ARM TRAVERSE.
GUARD RAILS AND SAFETY CHAINS CAN PREVENT PERSONNEL FROM ACCIDENTLY WALKING INTO THE ROBOT OPERATION AREA.

V. STEEL POSTS MOUNTED IN CONCRETE FLOORS SHOULD BE INSTALLED. PERSONNEL MAY BECOME TRAPPED BETWEEN THE ROBOT AND THE POST. IN INSTALLATION WHERE THE FULL SWEEP OF THE ROBOT'S ARM IS NOT USED, SAFETY CHAINS AND GUARD RAILS MAY BE PLACED INSIDE ITS REACH TO SAVE FLOOR SPACE.

VI. DO NOT PRESS ARM POWER OFF BUTTON WHILE ARM IS MOVING OR HOLDING A WEIGHTED OBJECT EXACT FOR AN EMERGENCY STOP.

VII. BEFORE PLACING ROBOT IN "FREE" MODE, MAKE SURE ARM IS PROPERLY SUPPORTED AFTER PRESSING "FREE" BUTTON AND THE APPROPRIATE JOINT SWITCH, THAT JOINT BECOMES FREE-SWINGING. THE ARM MAY COLLAPSE CAUSING DAMAGE TO ITSELF OR ITS SURROUNDINGS.

VIII. OPERATORS MAY BE IN DANGER OF RECEIVING ELECTRICAL SHOCKS, OR TRIPPING OVER LOOSE CABLES, OR OF SOME OTHER MISFORTUNE IF CAUTION IS NOT OBSERVED.
-COVERS PROTECTING HIGH VOLTAGE CIRCUITS MUST NOT BE REMOVED.
-LOOSE CABLES, HOSES, AND WIRES MUST BE ADEQUATELY SUPPORTED.
-THE ROBOT BODY MUST BE EFFICIENTLY GROUNDED.
-ELECTRIC TOOLS LIKE SPOT WELDING GUNS MUST HAVE THEIR CASES CONNECTED TO THE GROUND.

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ROBOT SAFETY

SENSORS MAY BE USED TO PROTECT THE ROBOT FROM COLLISIONS WITH OBJECTS AND PERSONNEL WHO INADVERTENTLY WANDER INTO THE ROBOT OPERATION.

I. EXTERNAL SENSORS
  A. PRESSURE SENSITIVE MATS
    SETS OFF AUDIBLE MATS
  B. LIGHT CURTAINS
    SHUT ROBOT OFF WHEN SOMEONE COMES WITHIN REACH
  C. LIGHT BEAM BARRIERS
    PLACED AROUND NORMAL WORKING VOLUME OF ROBOT. IF THE ARM BREAKS THE BEAM THEN THE ARM IS SHUT DOWN.
    . PLACED AROUND ROBOT OPERATION AREA. IF PERSONNEL STEP INTO THE ROBOT WORKING VOLUME, THE BEAM IS BROKEN AND THE ROBOT IS SHUT DOWN.
  D. ARM MOUNTED KILL SWITCHES
    CAT-WHISKER FEELERS, ULTRASONIC RANGING DEVICES, INFRARED PROXIMITY DETECTOR.
  E. MULTIPLE ACTUATORS
    ON EACH JOINT SO THAT ONE COULD FAIL WITHOUT MAKING THE ROBOT DROP WHAT IT IS CARRYING.

II. INTERNAL SENSORS
  A. SENSORS USE TO MONITOR INTERNAL HAZARD CONDITIONS.
    PNEUMATIC PRESSURE
    HYDRAULIC PRESSURE
    LOSS OF LINE VOLTAGE
    EXCESSIVE TEMPERATURE
    1. SPEED
    2. ACCELERATION
    3. FORCE
    FLOW RESTRICTION: IN A HYDRAULIC SYSTEM A MANIPULATOR WITH HYDRAULIC ACTUATORS WHICH ENABLE THE ROBOT TO LIFT ITS RATED LOAD BUT ALSO PREVENTING IT FROM MOVING AT FULL SPEED.
  B. HARDWARE OR SOFTWARE CAN MONITOR THE SIGNALS FROM THE SENSOR DEVICES.

III. ROBOT

A. ROBOT SERVOS AND WIRING SHOULD BE KEPT INTERNAL TO PROTECT FROM HOSTILE ENVIRONMENTS.

B. MACHINE CHIPS ARE DANGEROUS AS THEY MAY GET CAUGHT UP IN THE ROBOT'S WRIST.

C. THE ROBOT'S OUTER BODY MUST BE STRONG ENOUGH TO WITHSTAND WATER SPRAY FROM COOLING BATHS, SPARKS, HYDRAULIC OIL LEAKS, ETC.

D. CLIP ON OR WIRE ON THERMAL INSULATION CAN BE SECURED TO THE ROBOT TO PROTECT IT FROM HIGH TEMPERATURES.

E. PLASTICS ARE USED TO PROTECT THE ROBOT FROM CORROSIVE MATERIALS WHICH COULD CAUSE DETERIORATION.

F. SHIELDS ARE USED TO PROTECT THE ROBOTS BODY FROM VERY HOT METAL PARTICLES.

G. IN SPRAY PAINTING AREAS THE VAPORS MAY BE HIGHLY EXPLOSIVE. SPARKS FROM ELECTRICAL ARCING MAY CAUSE AN EXPLOSION.

I. MAINTENANCE SAFETY
    A. ROBOT MAINTENANCE
        1. ALL POWER MUST BE SHUT DOWN.
        2. ALL HYDRAULIC AND AIR POWER SHOULD BE REMOVED.
        3. ARM MUST BE SUPPORTED TO PREVENT COLLAPSE.

II. CABLES TO ANY CONNECTION POST MUST NEVER BE INSERTED OR WITHDRAWN UNLESS POWER HAS BEEN REMOVED FROM ARM.

III. TURN OFF ALL CONTROLLER POWER AND UNPLUG CONTROLLER FROM LINE POWER BEFORE REMOVING OR INSTALLING A FUSE.

IV. START ROBOT ARM MOTION AT SLOW SPEED, WHEN ARM PATHS ARE FULLY DEFINED AND TESTED, SPEED MAY BE INCREASED.

LESSON PLAN #3

UNIT 4--SAFETY

ASSIGNMENT SHEET 1

AFTER READING THE INFORMATION SHEET IS4-3-1 PROVIDED, COMPLETE THE FOLLOWING QUESTIONS IN WRITING AS REQUESTED BY YOUR INSTRUCTOR.

1. WHAT IS THE LIGHT CURTAINS USED FOR IN A ROBOT SAFETY ENVIRONMENT?

2. WHERE ARE THE LIGHT BEAM BARRIERS PUT ON AND WHY ARE THEY USED AS EXTERNAL SENSORS FOR THE ROBOTS?

3. WHAT SAFETY PRECAUTIONS SHOULD BE TAKEN WHEN MAINTAINING A ROBOT?

4. TURN OFF CONTROLLER POWER AND UNPLUG CONTROLLER FROM LINE POWER BEFORE REMOVING OR INSTALLING A _____.

5. START ROBOT ARM MOTION AT _____ SPEED, WHEN ARM PATHS ARE FULLY DEFINED AND TESTED, SPEED MAY BE __________.